NUCLEAR ENGINEERING VOL. 5 NO. 47 APRIL, 1960

Beryllium and the AGR

THE new machining facility opened by Armstrong-Whitworth Aircraft (pp. 176-7) further emphasizes the confidence British industry is placing in the potential of the metal beryllium. This company has invested a considerable amount of capital in the plant, as have T.I. and I.C.I. in their beryllium tube extrusion facilities, not to mention the consortia in their research installations. The Authority has for some years been expending much effort on beryllium development at its various establishments, not least of these being AWRE.

All this adds up to a great deal of faith in the future of beryllium as a nuclear metal, although in the fulness of time the tonnage used in other fields of engineering is likely to overshadow its applications in nuclear engineering. There is little doubt that this metal with its high strength-to-weight ratio—already to be reckoned with in missile work—will find a place amongst the standard engineering metals; this prospect has no doubt influenced companies contemplating investment at this stage, although it is in atomic energy that the bulk of the initial work is expected.

So great has been the total effort in the U.K. that it would be indeed surprising if, from the metallurgical point of view, success did not result. One of the main hurdles—the limited ductility resulting from preferred orientation—would appear to have been surmounted. Tubes have been drawn and subsequently cold bent in a 5-in. radius and although the mass production of fuel cans of high integrity has yet to be achieved the feasibility has been proved. Machining and joining are unlikely to present undue problems.

Whereas a few years ago the physics characteristics of a beryllium-canned fuel, leading to a positive temperature coefficient, would have practically ruled out its use, control experts now regard the fundamental issues as decided by the acceptance of a positive coefficient on Magnox stations with high burn-up. There still has to be a certain eating of words in high places and the probability of a positive prompt coefficient would seem to indicate a fairly basic change from the Magnox characteristics, but the attitude appears to be that we have already learned to live with this type of condition and the AGR will merely require an extension of principles already accepted. Experimental confirmation of the theoretical predictions is still, of course, required.

From the chemical point of view the essential compatibility has already been established which leaves as the great unknown the radiation resistance and the burn-up that can be achieved. Certain preliminary experiments have been made but the results are open to wide interpretation; more important is it that there would seem to be no fundamental barrier to the production of a fuel can able to withstand several thousand MWd/t; whether the immediate results will be disappointing or encouraging has yet to be seen. Even if initial burn-ups are small, development of much more resistant material may follow swiftly.

Such are the problems and such is the justification for the extensive research and development and for the AGR family of exponential experiments, critical assemblies HERO and the AGR itself.

The decision to build or not to build a full-scale prototype has not rested entirely on the question of canning material—beryllium or stainless steel. In moving to higher temperatures a number of new engineering problems are involved and to gain experience of these, tenders for a (say) 300-MW plant could have been sought in the next few months. In such a case the canning material chosen would almost certainly have been stainless steel but that would not have meant anything more than that our knowledge of stainless steel behaviour was rated greater than our knowledge of beryllium at this point in time. It now seems most improbable that requests to tender for a full-scale AGR will go out for another two years at least and there seems little doubt that unless the development of the Oldbury site is for other reasons much delayed (the date for the public inquiry has already been fixed) this station will house Magnox reactors (to the tune of around 600 MW in the first instance). As a result the question of beryllium or stainless steel is scarcely relevant at present and until the AGR has been operational for some time, or at least a great deal of loop data obtained, attempts to answer it can only be abortive.

What is, perhaps, relevant at this stage of developments is the question just where will an AGR fit into a reactor complex consisting of Magnox, fast reactor and HTGC station should these all progress satisfactorily? The Generating Board is known to place great faith in the ultimate functions of the fast reactor and the total world effort being devoted to the system is formidable. Should the experiments on the DFR, the Russian fast reactor and the U.S. EBR-2 and the American experience on the Enrico Fermi plant proceed with anything approaching smoothness we could well see a British prototype—already on the drawing boards of the D and E Group—assuming reality before so very long and commercial designs completed in this decade.

So, too, with the HTGC project for which the zero high temperature facility ZENITH will have been in operation some 12 months or more before HERO.

When Calder Hall first became operational and the potential of the Magnox stations was appreciated, a number of authorities made the point that the original concept of Stage 1, Stage 2 and Stage 3 reactors was obsolete, but over the past two years we have slipped back into the philosophy that they are necessary chiefly (initially) as reactors for export markets—now no longer regarded as existing. Reductions in element production and fuel processing costs have laid stress on the value of standardizing components—particularly fuel elements and the economic advantages that accrue, but even ignoring this aspect it is not expected that the first AGR power stations would have capital costs below those of the Magnox stations and fuel costs would inevitably be appreciably higher. Will there be an opportunity for the system to achieve its development potential and show a gain over the Magnox stations before being overtaken by even more advanced systems?

On the other hand, should the advanced systems prove more intractable than anticipated then the developed AGR will be the only indigenous low capital cost type, but how it will compare in economics with systems using hydrogenous moderators has yet to be assessed. Until burn-up data have been obtained and figures published on the price of enriched material and, equally important, on the cost of enriching uranium, valid comparisons cannot be made. The AGR is our insurance and it is clearly more comfortable to have a plurality of systems to choose from than a gap in the forward programme.

In the meantime we can be confident that the fundamental characteristics of beryllium will continue to receive intensive study and that even if its reign as a reactor canning material is short, future generations of engineers in other fields will be grateful for the work that has been done.

Radioactive Substances Bill

THE Radioactive Substances Bill was given its second reading in the House of Commons on March 7 and has now passed through to the final committee stage. Designed to control the disposal of radioactive wastes the Bill gives effect to the recommendations contained in the Control of Radioactive Wastes Report (Cmnd. 884) the clarity of which was commended by many speakers in the debate. Welcomed by members on both sides of the House the Bill provides for the registration of users of radioactive materials with the exception of the AEA and Government Departments and sites coming under the Nuclear Installations (Licensing and Insurance) Act. The Minister will lay down conditions governing disposal of wastes which in general will fall into three categories—those which can be handled by the normal sewers, those which can be disposed of by local authorities but require special precautions, and those which must be disposed of on a national basis. This last will be handled by the AEA for a trial period of two years after which the matter will be reconsidered and alternative arrangements made if this should prove necessary.

Once this Bill—which is long overdue—has been through the committee stages and passed its third reading (and judging by the present mood of the House its passage can be speedy) there will only remain the enactment of the Ministry of Labour and National Service Factories (Ionizing Radiations) Regulations (at the end of the year) for legislation governing radioactive materials in the U.K. to be considered reasonably well covered. It should be a source of gratification to all concerned that this will have been achieved without any serious malpractices having arisen in the interim period and without it being necessary to introduce legislation of such a restrictive nature that nuclear energy development need be materially hampered.

Nuclear Powered Merchant Ships

THE report of the Committee on the Safety of Nuclear Powered Merchant Ships was presented to the Ministry of Transport in November, 1959, and published as Cmnd. 958 in February. Set up in March, 1958, the committee was drawn from a variety of shipping interests and included representatives from the AEA. Its report is an impressive document and covers not only the design aspects of nuclear propelled ships but also operational requirements, safety of navigation, disposal of wastes, salvage and proposed responsibilities of the Government. In an appendix, proposed recommendations are put forward for adoption by the International Conference on the Safety of Life at Sea which convenes in London in May.

At one time it was feared that the rules proposed would be unduly restrictive on designers and that it would be difficult for some reactor systems already in an advanced stage of development to comply with them. An examination of the recommendations, however (pp. 169-171), shows that the main effort has been directed towards the establishing of principles rather than the drawing up of too specific rules.

The report is concerned with surface nuclear ships only and the committee make it quite clear they believe that nuclear ships can be built and operated within acceptable standards if the design principles, rules and procedures recommended are followed. The comprehensive nature of the report reflects great credit on the work of the committee and the Ministry and should prove an invaluable basis for discussion at the forthcoming conference. It is difficult to see how the bulk of its conclusions and recommendations can be faulted and it is to be hoped that international agreements on the lines proposed can follow swiftly.

DIGEST...

Surveying Significant News

Dungeness Tenders Under Study by CEGB

Three tenders have been received by the CEGB for the Dungeness 550 MW station. These were from The Nuclear Power Group (based on the original NPPC outline design), The English Electric-Taylor Woodrow-Babcock and Wilcox Group and from Atomic Power Constructions. Prices for this station will be high because of the appalling site conditions which civil engineers will have to contend with. These can add between £20 and £30/kW to the basic station cost.

Second Nuclear Sub to be Ordered : Naval Surface Ship Policy Undefined

During the debate on the Navy Estimates submitted in March it was made clear that a second British-made (including fuel) nuclear submarine would be ordered this year, based upon the *Dreadnought* and the British prototype under construction at Dounreay. No indication was given of the size of the nuclear submarine fleet anticipated nor of Admiralty policy with regard to nuclear-propelled surface vessels. Production of a nuclear-propelled missile launcher was urged in many quarters but answers were evasive. *Dreadnought* is to be launched in the autumn of this year.

APC, GEC Partnership Dissolved

The partnership between GEC and Atomic Power Constructions has been broken due to the difficulties of arranging the detailed responsibilities—and independence—of the joint holding company. It had previously been decided that GEC would not be tendering for Dungeness and APC are not likely to tender for Sizewell; on this basis alone the value of collaboration seemed small. There are thus, again, four tendering consortia in the U.K. which restores the situation to the 1956 position.

U.S.-Euratom Research Programme Under Discussion

Euratom is seeking to extend the joint research and development programme with the U.S. to cover reactor systems outside those included in the power demonstration programme. This additional flexibility is urged on the grounds of long term values and competition from the U.S.S.R. The U.S. AEC is countering by offering to hire enriched fuel rather than supply on a deferred payments basis as a further spur to power station construction.

DRAGON Budget and Information Exchange with U.S.

Proposals for an exchange of information between the DRAGON project and the U.S. AEC have been approved, the main U.S. company concerned being General Dynamics. Of its budget for 1960/61 totalling £2.83 million approximately one-third each will be spent on reactor plant and buildings, extra-mural research and development, and maintenance and work of the project staff at Winfrith.

Closer U.S.-Canadian Collaboration on Heavy Water Reactors

Negotiations are under way between the U.S. AEC and AECL towards an expanded programme of co-operation in the development of heavy water moderated reactors. This is on the lines of providing for the exchange of detailed information, closer co-ordination of research and development, exchange of personnel and subject to statutory authorization, a $5 million research programme sponsored by the U.S. AEC but directed towards the Canadian heavy water projects.

India Signs Agreement with U.S.S.R.

India has signed an agreement with the U.S.S.R. for collaboration in atomic energy developments. Immediately prior to this there had been a sudden cooling towards Britain as regards the possibility of ordering a power reactor largely it would appear on the political side, because of the restrictions to peaceful uses which would be attached to fuel agreements. India is very sensitive on the point of inspection. It had already become clear that without considerable modifications to standard U.S. practice the opportunity for American manufacturers in India was small. A team from America has, however, been touring India with a view to proposing modes of collaboration.

Canadian Diffusion Plant Proposed

Proposals for a uranium enriching plant to be built in Canada have been supported by the President of the Peace River Power Development Company who has stated that, on information received from the U.K., it would be possible to produce enriched uranium in the Peace River area in competition with present U.S. prices. It is maintained that enriched uranium could represent a most valuable export and would assist the uranium mining industry now entering a difficult phase.

Sale of Argonaut Types

The Dutch Nuclear Research Centre has placed with Hawker Siddeley an order for a 10 kW JASON research and training reactor to be installed at Petten; the reactor is scheduled to be completed in August. With a similar requirement, the Australian AEC has decided to purchase a U.S. reactor—a UTR-10 from American Standard.

AAEC Seventh Annual Report

The Australian Atomic Energy Commission's Seventh Annual Report for the year ended June 30, 1959, has now been published. It shows the net operating and capital expenditure for the 12 months as a little over £A2½ million as compared with nearly £A4 million for the previous year, and discusses the change in emphasis from the LMFR to the HTGC. Work on liquid metals is now largely restricted to sodium technology for irradiation experiments in HIFAR. It is estimated that the first nuclear power stations will be commissioned round about 1970 and between 1970 and 1980 a total installed capacity of 1,000 MW can be expected.

CEA Completes Modifications of G2

After something over 1,000 hours work inside the concrete pressure vessel of G2 the reactor has been started up again and is running at full power. When first put on load it was appreciated that part of the reactor vessel was running some 50° C above the design temperature but the decision was made to continue on load in order not to hold up delivery of plutonium for the French nuclear bomb. The reactor was then shut down and appropriate modifications made to the cooling system. These have also been incorporated in G3.

Fuel Supply Agreement with Japan Signed by AEA

Early in March the Japan Atomic Power Company signed with the Atomic Energy Authority a Heads of Contract Agreement covering the supply of natural uranium fuel for Tokai Mura. Details of the terms of guarantees and prices were not made available and it was claimed had not been worked out, although the general principles have clearly now been settled. The final agreement will be signed in about two years time.

Emergence of New British Research Reactor

As a result of collaboration between GEC and the Imperial College of Science and Technology a new 10 kW research reactor has been developed. Entitled the CONSORT the first of these is likely to be installed in the college's establishment at Ascot. GEC propose to market the reactor, an open-tank type, at a price of around £50,000.

Land Division of Lloyd's Register of Shipping Commitments

Following their early work on the Atomic Energy Authority's reactors and the first British nuclear power stations, Lloyd's, celebrating their 200th birthday, are also supervising the construction of the AGR pressure vessel at Windscale and other experimental plant at the AEA's establishments at Harwell, Winfrith and AWRE. In addition, an advisory contract has recently been undertaken for AB Atomenergi of Sweden, a full-time surveyor is at Latina in Italy, and the Society has recently been commissioned to undertake an inspection of the BWR plant for Cuba and the GEC Station at Tokai Mura—a most impressive range of installations.

Reactor Briefs

The 5 MW light-water moderated and cooled reactor, HERALD, at Aldermaston, critical on February 29. . . . The pressurized water reactor that will power the U.S. Savannah went critical for a trial period at Babcock and Wilcox's laboratory, Lynchburg, on February 23. . . . Criticality was achieved on February 23 by the gas-cooled Reactor Experiment No. 1 of the U.S.AEC at the National Reactor Testing Station, Idaho. . . . The AGN-201 tank-type reactor at the University of Palermo, Italy, went critical on February 29. . . . It has been reported by Tass that a new experimental reactor has been commissioned in Kiev.

HERO

Its Place in the AGR Development Programme

The apparent anomaly of a zero-energy reactor being completed at the same time as its power counterpart is discussed in this article, which reviews the development programme as a whole.

IDEALLY, the development of a power reactor system takes place in a number of successive stages. In parallel with the basic engineering and metallurgy research, physics experiments are performed on exponential stacks, leading to the construction of a zero energy facility and thence to an experimental reactor and a prototype. The need to compress the time scale, however, tends to distort the logical order and leads to considerable overlapping of the preliminary phases. This is demonstrated in the AGR programme where HERO, the AGR's high temperature zero energy reactor, will be completed at about the same time (April, 1961) as the reactor experiment.

Work by the BICEP Team

Research on gas-cooled graphite-moderated systems using enriched ceramic fuel is proceeding on a number of fronts. At Winfrith the BICEP team have largely completed their work on natural uranium rods and are now turning their attention to enriched material and fuel bundles. Extensive measurements on an exponential stack with differing channel dimensions and differing fuel geometries enable calculated flux distributions to be compared with practice and the equation constants to be adjusted so that at least self-consistency is achieved and the behaviour of new lattices predicted with precision. The BICEP team expect to be in a position to predict the reactivity of AGR systems from the lattice geometry with reasonable accuracy in 6-9 months time.

Exponential Experiments

The use of enriched uranium presents certain new problems in the extrapolation of exponential data to full-scale reactors owing to limitations imposed by criticality on stack size. To gain confidence in the extrapolation of small stack data an exponential experiment based on Calder parameters has been built at Windscale. This will be followed by a fine structure stack to be ready in July and a general-purpose stack a little later. The general-purpose assembly will allow the small stack extrapolation problem to be tackled in three ways. As alternatives to a small stack which can be constructed in the facility—similar to a second experiment at Winfrith—mixed (i.e., with natural uranium) fuels or approach-to-critical techniques can be employed. More elaborate controls and shielding than usually encountered in sub-critical assemblies will be necessary to allow this. An accelerator neutron source will be available as this is shown to be more economic than Sb-Be sources irradiated in Calder.

In the meantime heat transfer work is proceeding on a 36-rod bundle to determine the optimum spacings for maximum heat output—neutron screening of the inner rods allows them to be more closely spaced. This work is at present based on a theoretical assessment of the neutron flux and fine structure experimental confirmation is required.

Although much physics data can be obtained from AGR itself the complexity of the core top, including the hot box or coolant manifold, limits the flexibility of the system. Furthermore, the reactor is required to provide data on fuel element behaviour and the experimental channels will be in continuous use. A high load factor is demanded and regular interruptions to the power operation for physics measurements cannot be tolerated. A statistical assessment of the burn-up that can be achieved with different elements has overriding priority. The cost of the additional enrichment necessary if stainless-steel cans are used in place of beryllium means that a considerably higher burn-up must be achieved in the former, if generation costs are to be the same.

The Experimental Programme

Initially, both AGR and HERO will be built with small cores and the behaviour of the systems compared whilst some detailed flux measurements are made on HERO. Then full-size cores will be built up (possibly with an intermediate stage), which will include absorbers for coarse control of reactivity. While AGR concentrates on fuel-element testing, detailed work will be done on HERO of the flux distributions, temperature coefficients and so on with the larger core. As HERO can be kept at uniform temperature with the central channels if necessary at a lower temperature, it will be possible to assign real values to the temperature coefficients. This is of particular importance as the control problem of AGR is complicated by the use of a moderator (beryllium) as a canning material which materially alters the normally large negative fuel temperature coefficient.

Higher burn-up core conditions can be simulated in HERO by the introduction of simulated poisons. When the work is complete on the large core it is proposed to move back to smaller cores to make elaborate measurements with both beryllium and stainless-steel loadings. The general programme also envisages the assessment of the loop conditions that will prevail in AGR.

This phase of the work is expected to take about 18 months after which a more thorough study will be made of high burn-up cores, i.e., with a significant plutonium content. It is possible that the programme will then concentrate on the lattice measurement in cores corresponding to civilian reactor designs.

While it would have been more convenient for HERO to have been in operation many months before AGR the simultaneous timing in no way lessens the value of the contribution that this reactor can make.

HERO—
Design and Construction

Construction of this reactor is at an early stage and contracts have not yet been placed for all of the detail equipment. The major design parameters have, however, now been frozen and the reactor is scheduled to come into operation in April, 1961.

THE site selected for HERO is the old West blower house of the Windscale No. 1 pile. So far, one-half of the house has been taken over, and the construction of HERO is proceeding at the southerly end, while at the other, separated by a partition, are being constructed in light-sealed structures, the exponential experiments. The old filter galleries and the space underneath them are being utilized for control room, change room, ventilation plant, offices, CO_2 and graphite stores, battery and electrical plant rooms, workshops, etc. The HERO plant room is being built at a level a few feet above the original floor level.

The reactor room (i.e., charge-discharge room) is on top of the reactor itself, and is therefore, considerably higher than the existing roof.

Main contractors for the civil engineering work are Whatlings, Ltd., structural steelwork being undertaken by Robert Watson and Co. (Constructional Engineers), Ltd.

Although this is a zero-energy reactor (the maximum power will actually be a maximum of 3 kW for short periods) as the programme includes work with beryllium and, at a later date, with plutonium, containment is necessary. The reactor is housed in a cylinder of reinforced concrete 4 ft thick within which is located what in a power reactor would be the pressure vessel, but can hardly be termed this in HERO, as the system normally operates within 1-2 p.s.i. of atmospheric pressure; the specification called for the vessel and primary circuits to be vacuum tight.

The vessel, being manufactured by Ashmore, Benson, Pease and Co., Ltd., is of stainless steel, as absolute cleanliness is required. With an inside diameter of 21 ft and an overall length of 46 ft 3½ in. it will be the largest stainless-steel vessel ever built in this country, it is believed. Plate thickness is ½ in. It is supported on 12 legs, which are extended through the vessel to support the diagrid for the graphite. In addition to ports, located towards the lower end, for gas circulation, it has a manhole located above the top level of the graphite stack for access; a walkway and ladder system is provided between the concrete and the vessel to assist in this. There are 60 standpipes in the top dome, and 11 stub ends in the bottom dome, in which cooled ion chambers and fission chambers, for the operating instrumentation, may be inserted in re-entrant tubes. The vessel is covered with 6-in. lagging.

Graphite

The graphite stack of HERO is of particular interest in that it is possible to rebuild it to a different lattice at a later date. And, for this reason, its actual make-up differs widely from AGR in that the bricks are smaller, and there are spacing pieces between the bricks, which can be removed when rebuilding is necessary. At present, it is to be built with a triangular lattice of 10.75 in.; the proposed later pitch is 9.48 in. The first stack will have 253 fuel channels, with 72 in the reflector (total 325); the corresponding figure for the smaller pitch is 433. Six of the fuel channels are made oversize for absorbers simulating loop systems in AGR.

There is provision for a large central hole to accommodate an oscillator; there are also 12 holes for safety rods.

Flux-plotting holes are also provided, arranged in six radial lines (3 diameters) the total number being 63 (12 per radius).

Since, for nuclear reasons (neutron streaming) it is desirable to have solid graphite where positions are not occupied by fuel elements, control rods, etc., all holes in the core are arranged to be plugged with graphite dowels to be removed as necessary. As a reasonable compromise between the inconvenience of individual dowels for each brick, and the liability to damage of graphite in long lengths, it has been decided to use dowels in lengths of a little over 2 ft, so that the height of the stack can be covered by about seven sections, removable in the same manner as a fuel element.

The stack is 12-sided, approximately 17 ft 8½ in. across flats, with a core height of 14 ft and a 2 ft reflector layer top and bottom, giving a total height of 18 ft. The graphite is being manufactured by the Anglo-Great Lakes Co., Ltd., and Achesons Colloids, Ltd., the machining being divided between English Electric and the Authority's own workshops at Windscale.

Fuel Handling

The fuel differs in detail from the AGR fuel, being made up in shorter lengths. While the basic bundle (i.e., 36 rods each 1 ft long) is the same, HERO takes its fuel in assemblies about 3 ft 6 in. long comprised of three bundles with beryllium spacers, the whole being contained in a graphite sleeve and secured by a central tube (thin-walled stainless steel ½ in. diameter) with a lock-nut on one end and a lifting head on the other, four such elements constituting a charge for one hole. In AGR, of course, the charge is made up in one stringer approximately 14-ft long. Adopting this system for HERO would greatly increase the cost, not only for the extra height required in the reactor room, but inside the vessel itself. A moment's thought will show that it is not possible to arrange standpipes immediately above the fuel holes: even if differential expansion (said to total nearly 9 in.) did not preclude this, the change in lattice at a later date would certainly do so.

HERO, then, will have to be fuelled "blind." The charge machine, under development by Rubery, Owen and Co., Ltd., will be accurately indexed for angular motion as well as radius; it will be necessary to chart the "bearings" of each hole from its associated standpipe, correction being made for the temperature of the graphite at the time.

The course of the fuel from storage to graphite can be seen from the general arrangement, Fig. 1. The fuel store

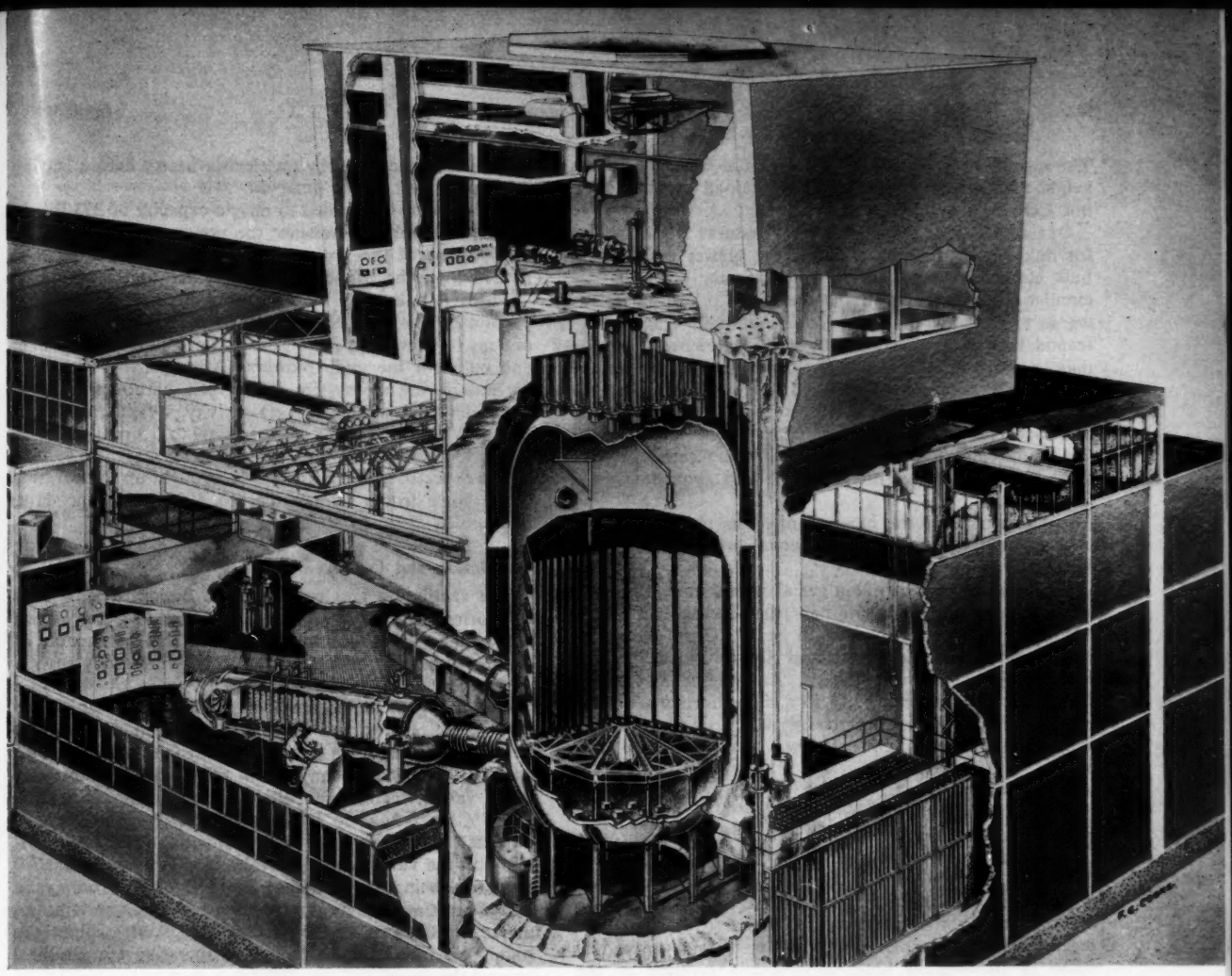


Fig. 1.—Cutaway drawing of HERO showing general arrangement of reactor and auxiliary plant.

(which has been designed with an eye on accidental criticality) has capacity for 224 tubular containers of mild steel 5½ in. diameter and 15 ft. long, with snap-fastener lids and lifting lugs, each containing one complete charge. Lifted out of the rack by the crane the container is transferred to one of the two " turntable " mechanisms, the lid removed, and the container positioned under one of the two vertical tubes leading to holes in the operating floor, through which the elements are picked up into the charging machine. By the use of two charging machines, one picking up fuel whilst the other is loading it into the reactor, it is expected to load one channel in approximately 1 hour. Sealing of the charging machine on the standpipe is not expected to present any particular difficulty; there is no question of the gas being under pressure, and the cooling of the reactor top has been so thoroughly investigated that the standpipes are not expected to exceed 20°C, so that rubber sealing arrangements can be used.

Control

The control arrangements, which can be varied to suit the system under investigation, normally consist of two fine, six safety, and up to 14 coarse rods. The control-rod mechanisms (Vickers-Armstrongs) have a number of interesting features.

Since the control system presents the same problem as the fuelling—the inability to ensure coincidence of standpipe and stack hole—these mechanisms must be suitable for " round-the-corner " operation, and similar radial and axial movements are required.

The mechanisms are of the winch type, the drum being driven by chain through a magnetic clutch. Between the sprocket of the chain drive and the variable-frequency motor is a gear train which includes a pair of pinions mounted on stub shafts outside the gearbox: these gears are readily removable and replaceable by another pair of different numbers of teeth; up to five different gear ratios can be obtained in this manner.

The winding drum is of the helically grooved type and, by means of a screw mechanism, is caused to move along the shaft as it rotates, thus ensuring that the wire rope always leads off the drum in the same vertical plane.

All mechanisms, except those for the fine control rods, are fitted with emergency dropping gear for scram purposes, consisting of the clutch already mentioned, with a hydraulic brake which can be coupled to the drum through a nylon-faced dog-clutch that is normally " out," but is engaged during the last two feet of travel. It is stated that this will permit dropping the rods the full 14 ft in 1¼ sec after a scram signal is received; the first 12 ft being covered in 1 sec.

Gas Circuits

A zero-energy reactor for high-temperature operation requires heating, not cooling, and what is normally regarded as the " coolant " circuit can hardly be so described, although cooling can be applied when necessary.

The maximum operating temperature for HERO is in the neighbourhood of 500°C (933°F), obtained by circulating hot CO_2 by two blower equipments.

One of HERO's most interesting features is the facility for dual-temperature operation. One blower operates on bulk circulation, blowing from beneath the core, the gas circulation being through the core and returning downwards around the periphery of the graphite stack. The second blower, however, can be arranged to heat only the middle 19 channels, and it is possible to operate with a substantial difference in temperature on the two circuits so that independent measurements can be made of temperature coefficients of fuel and bulk graphite. Connection between the gas circuits and the blowers is by concentric bellows ducts passing through the concrete containment to the plant room.

The contract for the blower units was placed with the de Havilland Engine Co., Ltd. (now part of the Hawker Siddeley Group).

The difficulties of handling gas at high temperatures are considerable, particularly when the leakage must be negligible, due to possible health hazards from beryllium canning material, and time could not be spared for the extensive development required. An acceptable solution was to cool the incoming gas to a more normal temperature, and reheat it on the discharge side, using a regenerative heat exchanger to reduce the heat losses to a reasonable amount.

A cutaway view of a blower unit is shown in Fig. 2, and a simplified diagram of the gas flow is shown in Fig. 3. Gas entering through the outer duct passes through the heat exchanger, giving up some of its heat to the cool gas from the blower, and then passes through a water-cooled heat exchanger, being reduced to about 50-70°C before entering the blower, after which it re-enters the regenerative heat exchanger on the "cold" side to recover some of its original heat; it is finally brought to the operating temperature by an electric heater before leaving the blower unit by the inner duct.

Each blower is specified to have a capacity of 233 lb/min CO_2 at atmospheric pressure; the pressure head across the unit will be of the order of $3\frac{1}{2}$ p.s.i. The motor is rated at 275 h.p.; the capacity of the heater unit is 450 kW.

There is a by-pass loop for continuous filtration of a portion of the gas. No separate blower is used; the loop obtains its flow from the differential pressure between inlet and outlet of the main blowers. Arrangements are made for monitoring the system for oxygen, carbon monoxide, beryllium, and alpha and beta activity. Vacuum plant is also provided for exhausting the vessel to 0.5 p.s.i. absolute pressure.

It is expected that HERO can be brought up to operating temperature (room temperature to 500°C) in four days, and cooled again in about the same time.

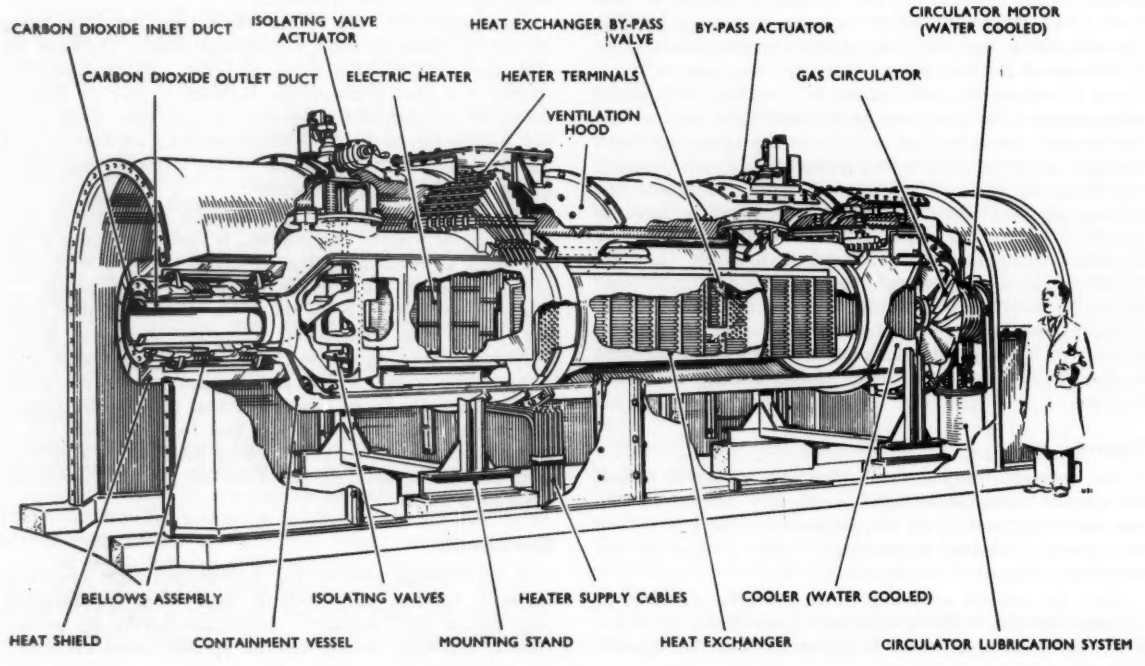
Ventilation and Cooling

The ventilation and cooling plant, besides dealing with the normal day-to-day requirements of the reactor (which are, in themselves, considerable) must also be capable of coping with any—admittedly unlikely—emergency involving beryllium and plutonium toxicity.

The plant, the main contract for which has been placed with R. B. Stirling and Co., Ltd., has been designed for almost any foreseeable incident. Both inlet and outlet air are filtered, and both can be shut off by valves shunted by relief valves. The inlet filter is a high-efficiency type (99.95% on 0-5μ, and 80% on 0.3μ specified). The two blowers (1 stand-by) each have a capacity of 13,000 cu ft/min and the ventilating air divides into two streams, 3,000 cu ft/min being supplied directly to the plant room, and 10,000 cu ft/min to the reactor room, from which it passes through interstices at the reactor top plant, around the standpipes (this explains their low operating temperature) around the vessel and out through a duct at the bottom of the reactor vault.

The outlet filter is specified as "absolute" (99.95% on 0.3μ).

Fig. 2.—Cutaway drawing of one of the de Havilland main blower units.



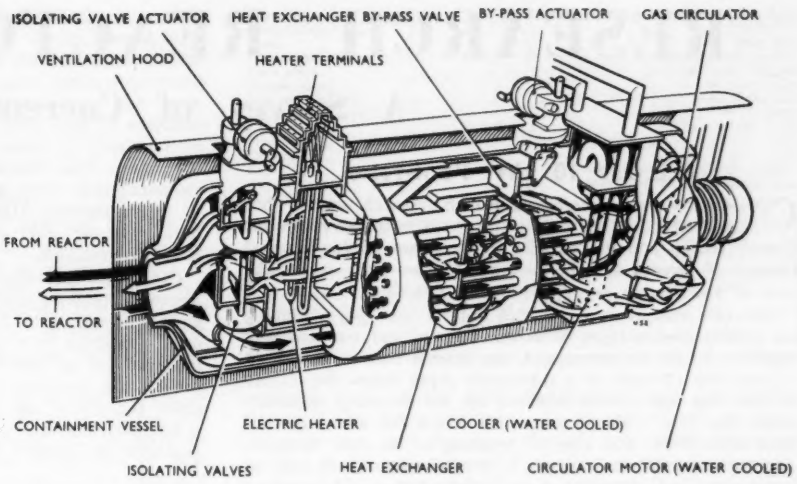


Fig. 3.—Simplified drawing of the gas flow through the blower, heat exchanger, heating and cooling circuits.

In the event of an incident which might lead to the release of toxicity, the inlet valve closes after a 1-min time lag, and the blowers are stopped. If fire or other consideration requires it, the outlet valve is closed manually and pressure rise occurring is vented through the filters, by the relief valves.

A separate cooling system with a capacity of about 100 cu ft/min is arranged for cooling the main ion chambers.

Flux and Temperature Measurements

Mention has already been made of the radial lines of flux-plotting holes in the core. Each of these holes has a stainless steel tube running from the top of the hole to the reactor top, and bunched so that all the tubes in one radial line are connected to a single standpipe, on which a foil-winding machine can be mounted in the same way as a charge-discharge machine or a control mechanism.

A foil-winding machine contains a number of strings or chains of short (about 3½ in.) graphite rods to act as foil carriers, each rod being linked to the next by a Hiduminium ball-and-socket joint. The chain is sufficiently flexible to be wound up and down, but when lowered into the hole, the ball joints allow the foil carriers to close up together, in effect forming a long graphite rod. After lowering into the hole and allowing the necessary irradiation period, the chain is wound up into the machine, which is then removed from the standpipe and placed over a storage hole, on a stand which raises it a little. The chain is now slowly lowered into the storage hole, the foils being removed for counting.

Another device under development is a fission chamber machine which, in a similar manner, will lower a fission chamber into the graphite. As this will entail a long lead between the fission chamber and the pre-amplifier some development work is required to produce a fission chamber with a built-in pulse transformer to operate at 500°C. This work is proceeding, and results are encouraging.

In addition to the many thermocouples that will be installed for special requirements, there will be a permanent installation of 35 for the routine running of the reactor. For the 19 channel experiment, 100 extra will be used, feeding into a data-recorder.

PRELIMINARY LIST OF CONTRACTORS

ANGLO GREAT LAKES CORPN., LTD., Newton Haugh, Newcastle upon Tyne.
Graphite.

ASHMORE, BENSON, PEASE AND CO., LTD., Parkfield Works, Stockton-on-Tees, Co. Durham.
Reactor vessel, including graphite support structure.

N. G. BAILEY, LTD., Heathcote, Ilkley, Yorks.
Electrical installation and wiring.

BRITISH ACHESON ELECTRODES, LTD., Grange Mill Lane, Wincobank, Sheffield.
Graphite.

BROOKHIRST IGRANIC, LTD., Igranic Works, Beds.
A.C. starters.

CONTACTOR SWITCHGEAR, LTD., Moorfield Road, Wolverhampton, Staffs.
D.C. motor starters.

D.P. BATTERY CO., LTD., Bakewell, Derbyshire.
D.C. switchboard.

DE HAVILLAND ENGINE CO., LTD., Leavesden, Herts.
Main blowers.

THE ENGLISH ELECTRIC CO., LTD., Marconi House, Strand, London, W.C.2.
Graphite machining.

SIR HOWARD GRUBB, PARSON AND CO., LTD., Walker Gate, Newcastle upon Tyne, 6.
Gas analysis main circuit (CO in CO_2).

MATTHEW HALL AND CO., LTD., 26 Dorset Square, London, N.W.1.
Steam heating, sprinkler system.

HALLAM, SLEIGH AND CHESTON, LTD., Oldfield Road, Maidenhead, Berks.
Control desks, panels and racks.

HILGER AND WATTS, LTD., 98 St. Pancras Way, London, N.W.1.
Gas analysis main circuit (Be in CO_2).

HILL (WEST BROMWICH), LTD., Albion Road, West Bromwich, Staffs.
Windows.

HONEYWELL-BROWN, LTD., Perivale, Greenford, Middx.
Temperature recorders.

IMPERIAL CHEMICAL INDUSTRIES, LTD., Thames House, Millbank, London, S.W.1.
CO_2 storage and equipment.

INTEGRA, LEEDS AND NORTHRUP, LTD., 183 Broad Street, Birmingham, 15.
Temperature recorders.

GEORGE KENT, LTD., Biscot Road, Luton, Beds.
Gas analysis main circuit (O_2 in CO_2).

MINERVA DETECTOR CO., LTD., Lower Mortlake Road, Richmond, Surrey.
Fire detection.

PIRELLI GENERAL CABLE WORKS, LTD., 343 Euston Road, London, N.W.1.
Main H.T. cabling.

PLOWRIGHT BROS., LTD., Shepley Street, Chesterfield, Derbys.
C.W. air-lock doors. Fuel-element storage tubes.

A. REYROLLE AND CO., LTD., Hebburn-on-Tyne, Co. Durham.
Switchgear.

RUBERY, OWEN AND CO., LTD., Whitegate Factory, Wrexham.
Charging equipment and chutes.

RUSTON AND HORNSBY, LTD., Lincoln.
Diesel generators.

LAURENCE SCOTT AND ELECTROMOTORS, LTD., Manfield House, Southampton Street, London, W.C.2.
Motor alternator.

STANDARD TELEPHONES AND CABLES, LTD., Connaught House, 63 Aldwych, London, W.C.2.
Telephone operation.

R. B. STERLING AND CO., Glasgow.
Ventilation and shield cooling.

VAUGHAN CRANE AND CO., LTD., West Gorton, Manchester, 12.
Reactor crane.

VICKERS ARMSTRONG (AIRCRAFT), LTD., Vickers House, Broadway, London, S.W.1.
Control rods and equipment.

ROBERT WATSON AND CO. (CONSTRUCTIONAL ENGINEERING), LTD., Bolton, Lancs.
Structural steelwork.

WHATLINGS, LTD., 10 Woodside Crescent, Glasgow, C.3.
Reactor vault, reactor room, biological shield, plant room, main buildings, transformer pens.

YORKSHIRE ELECTRIC TRANSFORMER, LTD., Thornhill, Dewsbury.
Transformers.

RESEARCH REACTORS

A Survey of Current Designs, Part 2

G.E.C.'s 10 kW Pool-type

CONSORT—a new low-priced British research reactor—has been designed jointly by the G.E.C.—Simon-Carves Atomic Energy Group and the nuclear power group at the Imperial College of Science and Technology, London University. The cost of the reactor is approximately £50,000.

The new reactor was designed with a view to combining the principal advantages of swimming-pool and enclosed-tank reactors. In the former design, the reactor core is housed in a large tank of water at a substantial depth below the surface so that the water itself provides all the shielding necessary above the core. This arrangement offers the advantages of good accessibility and ease of handling of the fuel elements. The enclosed-tank reactor uses a comparatively small tank of water with concrete shielding above the core as well as round the sides. The whole assembly is more compact than the swimming-pool type with the result that it is much easier to locate external experimental assemblies close to the core itself. On the other hand, a relatively complex fuel-handling system is required.

CONSORT provides an effective compromise between these designs, combining ease of fuel-handling with compactness and good accessibility to the core for experimental facilities. The core is located only 10 ft below the surface of the water moderator in an open-topped tank, but additional shielding is provided in the form of movable concrete-filled trolleys which cover the top of the tank while the reactor is in operation. It has been possible to incorporate an experimental bare face, protected by portable shielding blocks, closely adjacent to the

(Continued opposite at top of page 155)

A Reactor for University Training and Research

By P. J. GRANT, M.A., Ph.D.
and Professor J. M. KAY, M.A., Ph.D., M.I.Mech.E.
(Imperial College, London)

THE main functions of a university reactor are to provide post-graduate training in nuclear engineering and to act as a research tool in the fields of reactor engineering and reactor physics. It may also be useful to workers in other fields; for example for the production of radioactive isotopes, when these cannot conveniently be obtained elsewhere owing to their short half-life or the distance of the department from the source of supply, or for any investigation requiring reasonably high neutron or gamma ray fluxes.

When considering the type of reactor best suited to the needs of a university three points should be considered:—

(1) It is foolish to attempt to compete with the facilities of Government-operated reactors. For example, it is unlikely that irradiation experiments involving large-scale loops through a reactor core can be successfully performed with a university reactor; as another example, rather than attempt to produce long-lived isotopes it is usually better to purchase them elsewhere.

(2) On grounds both of safety and cost it is unwise to incorporate too many facilities in the reactor core. The correct approach is to provide a small number (producing only small reactivity effects) and to be able to place experimental systems close to the outside of the core but decoupled from it so far as reactivity is concerned. These external experimental facilities should be as flexible as possible.

(3) Bearing in mind the limited resources of a university department by comparison with a Government research establishment, routine operation should not involve any hazardous procedures. For example, as irradiated fuel is highly radioactive, all fuel handling operations should be simple and foolproof.

After consideration of the commercially available designs it was decided that the requirements of the Imperial College nuclear power group could best be met by a new design of low-power research reactor. This was undertaken jointly with the G.E.C.—Simon-Carves Atomic Energy Group and has resulted in the CONSORT reactor which has been recently announced.

The aim of the design is to combine some of the principal advantages of the swimming-pool and enclosed-tank types of reactor. Basically, CONSORT consists of a deep tank of small diameter with the core located about 10 ft below the surface of the water and surrounded by a monolithic concrete shield. Movable shielding trolleys cover the top of the tank when the reactor is operating. At the level of the core there are two rectangular flat surfaces in opposite walls of the tank and the concrete shield is cut away so that a large thermal column can be placed on one side while a bare face facility (protected when not in use by portable shielding blocks) is provided on the other. The rating of the reactor for continuous operation is 10 kW and, at this power level, a flux of 3×10^{10} thermal neutrons and 2×10^{10} fast neutrons is available at the bare face. This is a particularly versatile facility. In addition to the provision of a high neutron input in a horizontal direction into an experimental assembly, a vertical feed may be obtained, if desired, by the use of a dual-purpose thermal column. This consists of a horizontal column of graphite built against the bare face and having a vertical stub at its outer end. The neutron flux at the end of the stub may be optimized in strength and distribution by suitable voids in the graphite.

Access to the bare face may be obtained within 24 hours of reactor shut-down. It involves removal of the reactor core from its operating position and in CONSORT this operation has been designed to be particularly simple and safe. Fuel is transferred, by manual operation using a special handling tool, to shielded storage holes below the level of the core within the reactor tank. The water in the tank provides more than adequate shielding during this process and the fuel-handling tool is designed so that it limits the height to which a fuel element can be raised above the core.

Other experimental facilities are one (or more) beam tubes issuing radially from the reactor tank at core level and a vertical tube through the centre of the reactor to give access to the central reactor flux either for irradiation purposes or for oscillator experiments.

In addition to the technical and economic advantages claimed for CONSORT, the policy of designing a reactor in association with one of the industrial consortia to meet the special requirements of the nuclear power group at Imperial College has already proved to be of great value. It is of vital importance in a University engineering department that members of the lecturing staff should practise engineering in addition to teaching the subject. By taking part in the design of the reactor themselves, the staff of the nuclear power group are in a strong position to ensure that the maximum possible advantage is subsequently obtained from the engineering and research potentialities of the reactor.

reactor core, a most important facility for research and training purposes. When the reactor is shut down, the shielding trolleys can be withdrawn and manipulation of the fuel elements can then be carried out beneath the water, under direct observation by the operator using simple manual techniques. The whole design is based on the use of a well-proven type of enriched-uranium-alloy fuel element which is readily obtainable from the U.K. AEA.

Experimental Facilities

Designed primarily as a source of neutrons for use in experimental work for research and training purposes, CONSORT is rated at 10 kW. At this power level, a flux of approximately 3×10^{12} thermal neutrons and 2×10^{12} fast neutrons/cm² sec is available at an experimental face in the wall of the reactor tank adjacent to the core. A similar flux can also be obtained at the inner face of a graphite thermal column on the opposite side of the tank.

The core of the reactor is built up from between 20 and 24 fuel elements of the standard MTR type in which the enriched uranium-aluminium-alloy fuel is fabricated in the form of slightly curved plates clad in aluminium. A number of these plates are assembled to form an approximately square-sectioned element so that the coolant can flow between the faces of adjacent plates. The fuel elements are arranged vertically to form an approximately cylindrical core, each element being located at its lower end by a spigot which engages in a hole in an aluminium support plate. A hole through the spigot permits the water coolant to flow upwards between the fuel plates.

The core, with its support structure, is mounted near the bottom of a vertical cylindrical tank filled with water to act as moderator, coolant and shield. The tank, which is made of high-purity aluminium, ¼ in. thick, is open at the top, but a Perspex cover keeps the water surface free of dust.

In the vicinity of the core, two rectangular flat surfaces in opposite walls of the tank accommodate the experimental face and the thermal column. At the same level, the beam tubes project into the tank through tube stubs which are welded to the tank wall and blanked off at their inner ends.

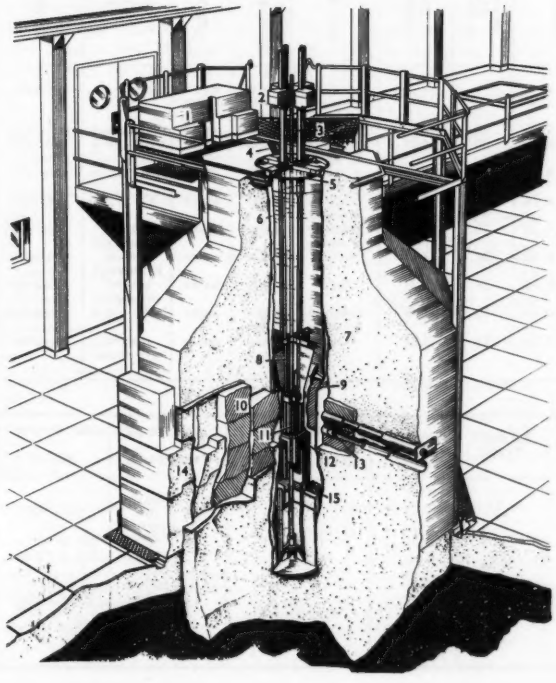
The tank is surrounded by a concrete biological shield, octagonal in plan, with a thickness of approximately 7 ft 6 in. reducing to 3 ft near the top of the tank. Axial shielding above the core consists of a 10-ft depth of water which is supplemented, while the reactor is in operation, by a 2 ft 6 in. thickness of concrete. This concrete shielding takes the form of two movable trolleys which run on guides set in the top face of the reactor structure, the joint between the trolleys being stepped and shaped to fit around the control-rod support tubes.

The reactor is controlled by means of vertical neutron-absorbing rods which are of flat section and pass through guide tubes between adjacent fuel elements. There are two shut-down rods, one fine-control rod and one safety rod.

Two alternative types of control-rod mechanism are available. In one design, the upper end of each rod is coupled, by means of an electromagnet, to a vertical rack moving between guide rollers. The rack is driven by a squirrel-cage induction motor through a gear-train from which the drive to the magslip rod-position indicator is also taken. If an emergency should arise, the electromagnets are automatically de-energized, thus releasing the rods from the racks and allowing them to fall into the core under gravity.

In the alternative arrangement, each rod is supported by a stainless-steel wire rope which passes over a pulley vertically above the rod and is then wound round a driving pulley mounted at the edge of the biological shield. This pulley is driven by a small geared motor through an electromagnetic clutch which, under "scram" conditions, is automatically released so that the rod falls into the core.

The 10 kW CONSORT which is being offered by G.E.C. Key: 1. Shielding Trolley, 2. Control Rod Mechanism, 3. Vertical Experimental Tube, 4. Channel for Water Connections, 5. Perspex Dust Cover, 6. Tank, 7. Biological Shield, 8. Control Rod, 9. Experimental Face, 10. Thermal Column, 11. Fuel Elements, 12. Core Support Plate, 13. Flux-measuring Instruments, 14. Concrete Shielding Blocks, 15. Shielding Plugs for Element Storage Holes.



Company	The GENERAL ELECTRIC Co., Ltd.
Designation	CONSORT
Type	Pool type
Application	Training and research
Basic price	Approximately £50,000
Power rating	10 kW continuous
Fuel enrichment	80-90% (or lower if desired)
Fuel element type	MTR plates
Core loading	2.5 to 3 kg of U-235
Moderator	H_2O
Coolant	H_2O
Shielding	Concrete, monolithic with movable blocks round experimental faces

Facility	Thermal flux n/cm² sec	Fast flux n/cm² sec
Bare face	3×10^{12}	2×10^{12}
Thermal column	up to 2×10^{12}	—
Oscillator hole	2×10^{11}	4×10^{11}
Beam tubes	up to 3×10^{12}	up to 10^{12}

General Electric (U.S.A.) Designs

THE Atomic Power Equipment Department of General Electric has completed or has in production a total of 13 research and test reactors varying from zero power critical facilities to the 30 MW General Electric Test Reactor.

NTR

The General Electric nuclear test reactor (NTR) is a solid fuel, water-cooled, graphite-moderated reactor designed as an industrial process control device. The core consists of an annular cylinder centred in a 5-ft cube of graphite. The core itself is constructed of uranium alloy discs on rods located in the annular aluminium container surrounding the central thermal column. The number of discs may be varied for reactivity as long as the excess is adequately compensated by control poison. The core cylinder is 19 in. long and 18 in. in diameter and is constructed of aluminium. The core produces a thermal flux of 3×10^7 neutrons/cm² per sec. per watt along its centreline. No coolant flow is required at low power levels. At power levels requiring coolant flow, water is used.

The nuclear test reactor can, with forced-water cooling, be operated at power levels up to 30 kW. At power levels up to 30 kW, the reactor will provide a sufficient supply of neutrons

to support many types of experiments using the thermal column, beam ports, and exposure holes.

OPR

High-performance General Electric Open Pool Reactors provide a large variety of experimental facilities for maximum utilization of neutron and gamma radiation. High-worth $\Delta k/k$ blade-type control elements contain sufficient negative reactivity so that the entire grid of the core can be filled with fuel elements and the reactor will still remain sub-critical, thus giving a higher margin of safety, and minimizing possibility of loading accidents. The high-worth blades will normally be withdrawn from the centre of the core, resulting in more uniform flux patterns in the core, beam ports, and vertical tubes. The fuel elements are made with a special G.E. pressure-bonding process. There are no brazed joints, thus no corrosion and poisoning from residual flux, and also no warping of the plates. Higher structural strength is also insured, and higher strength alloys may be used. A rigid suspension frame is all-welded, easily aligned and adjusted. Reactor bridge construction eliminates vibration of controls during personnel access, thus preventing false scram. Bolted to the suspension frame there is a grid box of cast aluminium. It provides high rigidity per unit weight with low-induced-radiation levels. Thus, there is a minimum of shutdown activity. Compensated ion chambers are protected from mechanical damage by being placed in the corner posts of the suspension frame, leaving free access to the core region; thus they cannot interfere with refuelling the reactor. All submerged reactor parts are easily accessible for remote handling. Modular core designs provide completely interchangeable fuel elements, reflector elements, radiation baskets, and source within the large grid area, for versatility of arrangement.

PTR

The General Electric Pool Training Reactor has been designed expressly for education and training applications. Using standard reactor components, and permitting maximum visual access to the reactor core, the PTR provides the student with a wide range of operating and observation experience. Utilizing full-scale open pool plate-type fuel elements, the student will become familiar with the problems of core-loading, control, handling and fuel storage. The instrumentation operates on the same principles as do full-scale facilities. The open pool concept offers many possibilities for broad classroom demonstrations, not possible in closed or encased core designs.

The PTR offers a wide range of possible experimental facility arrangements. With the core positioned in the centre of the pool, many experimental facility combinations are possible. The facility can be installed above ground with adequate concrete shielding, or below ground level utilizing the surrounding earth for shielding. Installation above ground makes possible a greater variety of experimental equipment.

GETR

The General Electric Test Reactor combines into a single reactor facility, the accessibility and flexibility of an open pool reactor with the high neutron fluxes of a pressurized test reactor. The arrangement leads to a facility capable of a wide variety of irradiation programmes under a large range of environmental conditions.

The 30-MW core which is water cooled and moderated, is contained in a small-diameter aluminium pressure vessel submerged in a water pool. The high neutron leakage from the reactor results in thermal flux peaking in the pool providing a large irradiation zone in the pool in addition to the in-core irradiation area.

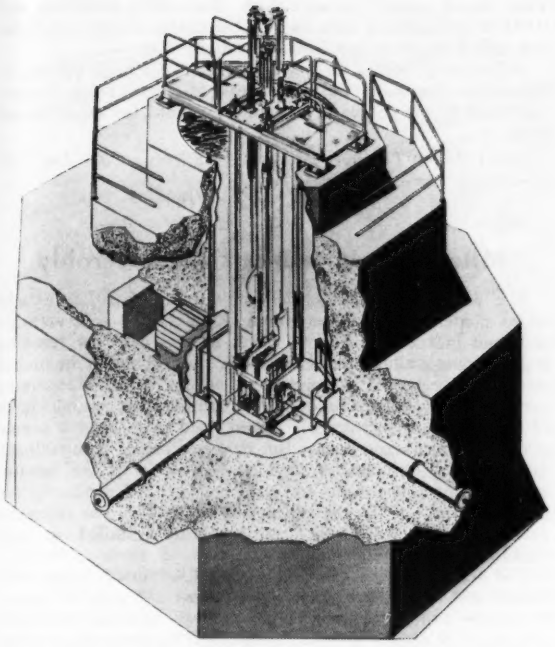
The GETR is simply and economically designed. The core is housed in a 24-in. (i.d.) aluminium tank, 23 ft long, which is located at the bottom of a 9-ft diameter pool. A stainless steel spool-piece extension accommodates a large number of in-core experimental leads at the top of the vessel. The pressure vessel is removable to accommodate revisions in core design.

The 2 ft x 2 ft core has an active length of 3 ft. It contains provision for 20 flat-plate-type fuel elements, eight filler pieces

GENERAL ELECTRIC (U.S.A.) RESEARCH AND TEST REACTORS

REACTOR	TYPE	APPLICATION	POWER	FUEL ENRICH.	FUEL TYPE	FUEL DIMENSION	NUMBER FUEL ELEMENTS	CORE LOADING	REFLECTOR	MODERATOR	COOLANT	FLOW	SHIELDING
NTR	—	Research	30 kW	93%	Disc	—	16	3KG	graphite	water	water	20 g.p.m.	concrete
RER	Tank	Test	10 mW	93%	Flat plate	3" × 3" × 24"	—	—	water	water	water	—	—
GETR	Tank	Test	30 MW	93%	Flat plate	3" × 3" × 36"	20	7.5	water	water	water	11,000g.p.m.	concrete
SPAIN	OPR	Research	3 MW	20%	Flat plate	3" × 3" × 24"	30	4.05	graphite & water	water	water	3,900 g.p.m.	concrete
VENEZUELA	OPR	Research	3 MW	20%	Flat plate	3" × 3" × 24"	30	4.05	graphite & water	water	water	3,900 g.p.m.	concrete
TAIWAN	OPR	Research	1 MW	20%	Flat plate	3" × 3" × 24"	30	4.05	graphite & water	water	water	1,500 g.p.m.	concrete
W.S.C.	OPR	Research	100 kW	93%	Flat plate	3" × 3" × 24"	26	3.1	graphite & water	water	water	natural circulation	concrete
STANFORD	PTR	Training	10 kW	93%	Flat plate	3" × 3" × 24"	24	3.24	graphite & water	water	water	natural circulation	concrete
W.P.I.	PTR	Training	1 kW	93%	Flat plate	3" × 3" × 24"	24	3.24	water	water	water	natural circulation	concrete
P.A.E.C.	OPR	Research	3 MW	20%	Flat plate	3" × 3" × 24"	30	4.05	graphite	water	water	1,700 r.p.m.	concrete
WISCONSIN	PTR	Training	10 kW	93%	Flat plate	3" × 3" × 24"	24	3.24	graphite & water	water	water	natural circulation	concrete

REACTOR	BEAM PORTS	THERMAL COLUMN	VERTICAL TUBES	THRU TUBE	RABBIT TUBE	FUEL LOOP	CAPSULE OR RAD. BASKET	AVERAGE CORE FLUX	
								THERMAL	FAST
NTR	—	1	1	—	—	—	1	10^7 nv/watt	—
RER	Radiation effects facility			—	—	—	—	5.5×10^{12}	2.4×10^{14}
GETR	1	—	—	—	1	7	47	1×10^{14}	4×10^{14}
SPAIN	6	1	2	2	—	—	5	1.7×10^{13}	5.9×10^{13}nv
VENEZUELA	6	2	—	2	2	—	5	1.7×10^{13}nv	5.9×10^{13}nv
TAIWAN	6	1	—	1	1	—	5	5.8×10^{12}nv	2×10^{13}nv
WSC	6	1	—	2	1	—	5	6.5×10^{11}nv	2×10^{13}nv
STANFORD	2	1	—	—	—	—	—	7×10^{10}nv	2.4×10^{11}nv
WPI	1	1	—	—	—	—	—	7×10^{9}	2.4×10^{19}
PAEC	6	1	—	—	2	—	5	1.7×10^{13}nv	5.9×10^{13}nv
WISCONSIN	4	1	—	—	—	—	5	7×10^{10}	2.4×10^{11}nv



From the range of research reactors made by General Electric (U.S.A.), the Pool Test Reactor (PTR) shown above is rated at 10 kW.

(each able to contain two capsule experiments), six bottom-driven control rods, a source, and space for three 3-in. through experimental facilities. The bottom-driven control rods simplify the reloading procedure. Core filler pieces are beryllium and support pieces between the fuel and vessel are beryllium and aluminium. The filler pieces help to maintain high flux in the core experimental facilities and prevent unrestricted coolant flow.

Fuel loading of the reactor is greatly influenced by the characteristics of the experiments. An initial fuel loading might be approximately 7 kg of U^{235}, permitting operation of the reactor for 25 days before refuelling is required. Fuel elements may be recycled to reduce fuel costs. Simplified refuelling through the top of the reactor tank is incorporated in the pool design. 11 ft of water is provided between the top of the tank and the pool for shielding during refuelling

(General Electric, Schenectady 5, New York.)

Company	A.M.F. ATOMICS
Designation	—
Type	(1) Tank; (2) Pool
Application	Research
No. installed	13
No. on order	—
Basic price	(1) $145,000; (2) $160,000
Power rating	10 kW
Fuel enrichment	90%
Fuel element type	MTR-type
Element dimensions	—
Core loading (element No.)	—
Core loading (wt. U–235)	(1) 3.6 kg; (2) 2.38 kg
Moderator	H_2O
Reflector	(1) H_2O; (2) graphite and H_2O
Coolant	H_2O
Coolant flow	—
Shielding	H_2O, concrete
Overall size	—

Hole and beam facilities	Thermal flux	Fast flux	Gamma flux
(4) 6-in. beam tubes, thermal columns, through tubes, bulk irrad. area, isotope production rabbits	(1) 7.7×10^{12} av n/cm² sec. (2) 1.3×10^{11} max n/cm² sec.	—	—

A.M.F. Pool and Tank Reactors

ONE of the world's most successful research reactor builders is American Machine and Foundry which, so far, has been concerned with the installation of some sixteen reactors. The majority of these units are based on an A.M.F. pool design, ratings being from 10 kW to 5MW but tank types are also available.

For example, the A.M.F. pool installed at Union Carbide Research Center is rated at 5 MW. The average neutron flux is 3×10^{13}/cm² sec.

The core comprises 25 fuel assemblies, each assembly consisting of 18 uranium-aluminium plates. These plates are made up of a layer of a uranium-aluminium alloy 0.020 in. thick, sandwiched between comparable thicknesses of pure aluminium sheathing. Critical mass is approx. 9 lb of enriched U^{235}.

The core rests in a grid mounted at the base of an aluminium tower suspended from a bridge over the pool. In operation, the core is submerged in approx. 25 ft of demineralized water.

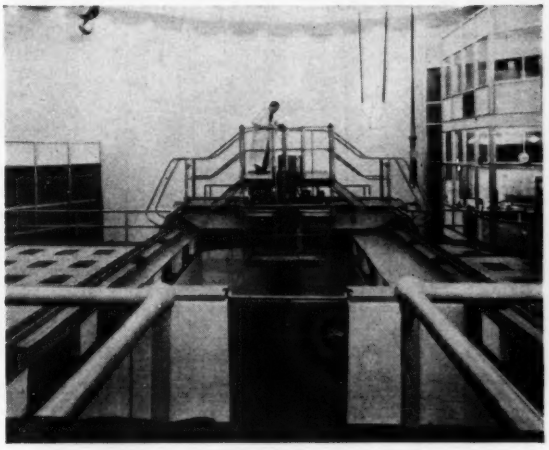
The pool enclosure is of concrete, and is divided into two bays. The reactor is designed so that the core can be moved from one bay to another to accommodate various requirements in research programmes. Half of the pool, 20 ft square and 30½ ft deep, is used for large equipment or materials to be exposed to radiation. In the centre of the other half there is an octagon-shaped stall. Here, six beam holes and a thermal column converge on the reactor core when it is in position.

The 10 kW A.M.F. tank-type reactor has a rectangular pool 4 ft by 4 ft 4 in. by 20 ft high; there is 16 ft of water above the core for shielding. The floor and sides of the pool are lined with ¼-in. aluminium plate, the lower part of the shielding being barytes concrete. There is a 20 ft high space some 15 in. wide by 18 in. deep for storing radioactive materials set in one side of the pool.

The MTR fuel assemblies are mounted on an aluminium grid plate with a 5 × 6 rectangular lattice. On three sides the core is reflected by graphite sealed in an aluminium can.

A.M.F. research reactors in operation or on order include a 1 MW pool at Battelle Memorial Institute, a 100 kW tank at Delft University, a 1 MW pool at Munich, 5 MW pool at Industrial Reactor Laboratories, the 10 MW heavy-water moderated JRR-2 at Tokai Mura, Japan, 1-5 MW pool at McMaster University, 1 MW pool at Athens, 1 MW pool for SORIN, Italy, 1 MW pool for JEN of Portugal, a 10 kW Educator (Argonaut type) in collaboration with G.N.E.C. for the University of Florida, a 1-5 MW pool at Rehovoth, Israel, a 100 kW tank for University of Buffalo, a 5 MW pool for Union Carbide, a 5-10 MW tank for Austria, 1 MW pool for Teheran University and a 1-5 MW pool for Puerto Rico.

(A.M.F. Atomics, Greenwich, Connecticut, U.S.A.)



For McMaster University, Hamilton, Ontario, American Machine and Foundry supplied a 1 MW pool reactor which can subsequently be converted to 5 MW.

A.E.I.'s 5 MW Merlin

DESIGNED for a thermal power of 5 MW, MERLIN—a medium flux research reactor—has been developed by A.E.I. and built by A.E.I.-J.T. as a private venture. Subsequently the company has received orders for similar reactors for AWRE, Aldermaston and for Germany.

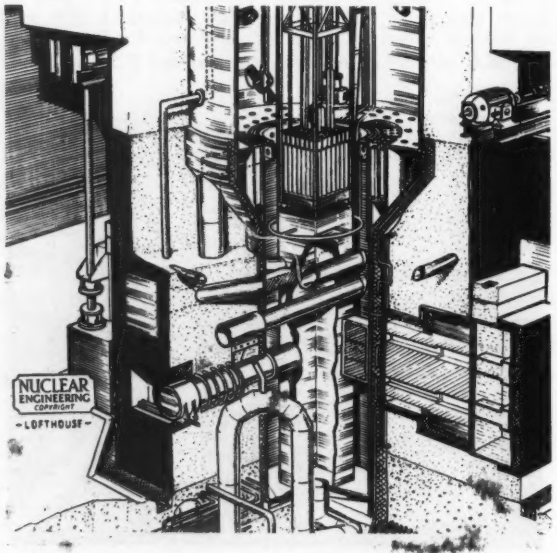
MERLIN is a pool type unit, the main bulk of the water being in an aluminium tank in two sections, the upper diameter being 11 ft 6 in. and the lower, 5 ft 6 in. The wall thickness is $\frac{3}{8}$ in. and the tank is surrounded by a concrete shield which is just over 6 ft thick for 14 ft above floor level and then 3 ft 6 in. thick to the top of the shield 28 ft above the floor.

The fuel elements consist of 14 plates in an open-ended aluminium box. Each plate is a uranium-aluminium alloy encased in an aluminium sheath. There are 10 g of U^{235} in each plate; the enrichment being more than 90%.

The core can be moved to any one of four positions. The top position permits the addition or withdrawal of fuel or experimental apparatus. Two lower positions bring the core into the plane of two sets of experimental facilities. The lowest, or storage position, is such that the entire core is below the level of the lowest beam hole. The core is cooled by primary water which is pumped into the side of the aluminium tank.

Company	A.E.I.—JOHN THOMPSON NUCLEAR ENERGY CO., LTD
Designation	MERLIN
Type	Pool, with four-position core
Application	Research, student training, testing
No. installed	3
No. on order	—
Basic price	
Power rating	5 MW
Fuel enrichment	93% (initial only)
Fuel element type	MTR: 14 plates per box
Element dimensions	23.6 in. long. Box: 2¾ in. sq.
Core loading (element No.)	20
Core loading (wt. U–235)	2.7 kg
Moderator	H_2O
Reflector	H_2O or berylllia
Coolant	H_2O
Coolant flow	1,900 g.p.m.
Shielding	4 in. lead, concrete
Overall size	—

Hole and beam facilities	Thermal flux	Fast flux	Gamma flux
Thermal col.	5×10^{13} n/cm² sec.	—	4×10^{6} r/h
(7) 4-in. horiz. holes			
(1) 3-in. vert. central, etc.			



MERLIN, a 5 MW medium flux research reactor by A.E.I., has a core which can be moved to one of four positions. This feature increases the number of different flux levels for various irradiation experiments.

Four reactor control units are used. Two safety devices control 0.055 δk in reactivity each, as does the coarse control, while the fine unit is equal to 0.005 δk in reactivity.

A feature of MERLIN is the provision of a large number of irradiation facilities, the usefulness of these being further increased by the choice of two core positions for experimental work.

(A.E.I.-John Thompson Nuclear Energy Co., Ltd., 33 Grosvenor Place, London, S.W.1.)

Miles Hivolt Sub-critical Assembly

The Miles Hivolt sub-critical unit, type BU.10, is a light water moderated natural uranium assembly. It is a versatile safe and inexpensive facility which can be used for teaching and for post-graduate research. The reactor uses a small but powerful accelerator to produce neutrons. This accelerator can be used as desired, either as a continuous or pulsed source of monoenergetic neutrons. When used as a pulsed source many advanced experiments can be performed. Although the accelerator is principally intended for use with the reactor, it is easily transportable and can be used independently for a great variety of nuclear physics experiments. The complete assembly, with accelerator, can be easily installed in any medium-sized laboratory.

The accelerator is a horizontal SAMES 150 kV J-type with pulsed and continuous output of between 10^9 and 10^{10} n/sec. Originally Miles Hivolt offered a French designed assembly known as URANIE—a vertical arrangement with the stack above the accelerator. The current design—developed by Miles Hivolt in collaboration with Dr. Walker of Birmingham University—is a horizontal unit which although requiring a greater floor area is more accessible. The first two Miles Hivolt assemblies are now being installed: one at Birmingham University (purchased with the assistance of D.S.I.R.) and the other at the Royal Naval College, Greenwich.

The sub-critical assembly uses natural uranium rods, canned in very high purity aluminium. These rods are 43¼ in. long and 1.22 in. in diameter. To avoid corrosion the water

MILES HIVOLT SUB-CRITICAL ASSEMBLY—SPECIFICATION

Fuel: Natural uranium bars 43¼ in. long, 1.22 in. diameter, encased in plain aluminium cans 0.04 in. thick. The full loading of fuel consists of 324 bars giving a total mass of about 5 tonnes (11,000 lb). Smaller amounts can, of course, be used in reflected assemblies.

Moderator: Light water of high purity, supplied by demineralizing plant which is part of the main equipment. The high purity is required to avoid corrosion.

Reflector: Two watertanks made of stainless steel are supplied. One, 44 in. by 34½ in. by 36½ in. high, fits closely around the lattice to give essentially an unreflected system. The second, 60 in. by 54 in. by 51 in. high, provides a minimum of 8 in. of water on the sides of the lattice; the amount above and below depends on the lattice position selected, but need not be less than 6 in. The smaller tank holds 200 gal (2,000 lb) of water and the larger one 650 gal (6,500 lb) without uranium being present. The full loading of uranium is equivalent to 68 gal.

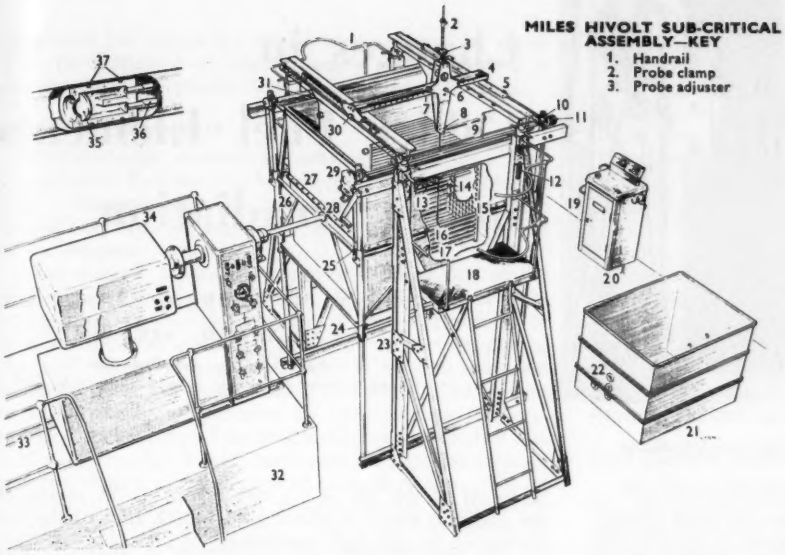
Lattice: The uranium bars are supported horizontally by an aluminium lattice plate at each end to form a square lattice of pitch 1.9 in. The pitch is constant over the whole lattice plate to an accuracy better than 0.005 in. Different lattice pitches can be obtained by using different plates.

Lattice Support Structure: The lattice plates are suspended from a gantry structure, to remove any problems of buckling, and spacing-pieces are available to enable the whole lattice structure to be placed at any of the three heights associated with the different positions of the source tube in the lattice.

Neutron Source: A source tube 1 in. in diameter passes horizontally through the system and is coupled to a deuteron accelerator. The deuterated or tritiated target for neutron production can be placed at any position in the tube. Holes in the tank and the lattice plate allow four possible positions for the source tube. An accelerator source of neutrons enables measurements to be made with both constant and time-dependent fluxes. Radioactive sources can be used for constant flux measurements and the system can be used as an orthodox exponential experiment by having sources of graphite placed outside the lattice.

Neutron Detectors: For constant fluxes, foils or electrical detectors (BF, counters, scintillation counters) can be used, but for time-dependent measurements the electrical detectors only can be used. A traversing head is supplied for accurate location of the detector at any point in the moderator.

k(eff.) and Neutron Multiplication: For the lattice arrangement quoted, and with a full loading of uranium k(eff.) for the unreflected case is about 0.88 and hence the neutron multiplication is about 0.8. With the reflected assembly the values are approximately 0.9 and 10.



MILES HIVOLT SUB-CRITICAL ASSEMBLY—KEY

1. Handrail
2. Probe clamp
3. Probe adjuster
4. Indexed longitudinal beam
5. Indexed lateral angle
6. Ball lock
7. Probe locator
8. Probe guide wheels
9. Lattice plate spacer
10. Lateral movement handwheel
11. Tank winch pulleys
12. Jacking screw and handwheel
13. Target (see detail)
14. Alternative target holes
15. Lattice plate
16. Probe
17. Fuel rods
18. Operator's platform
19. Water purifier
20. Purifier drain
21. Small tank (unreflected system)
22. Alternative target holes
23. End frame assembly
24. Tank cradle locating peg
25. Tank winch cable tensioner
26. Tank cradle
27. Large tank
28. Winch handle and extractor
29. Tank winch gear box
30. Ball lock
31. Lateral movement cable tensioner
32. Concrete plinth
33. Alignment rails
34. Particle accelerator

DETAILS OF TARGET

35. Target
36. Cooling water pipes
37. "O" type sealing rings

moderator must be maintained to a high degree of purity, this being achieved by a special ion exchange deionization plant. The reactor is designed for easy access to the uranium rods, lattice plates and neutron targets so that they can be rearranged, changed or replaced, as necessary.

The standard lattice plates are designed to form a square lattice of pitch 1.9 in. carrying 340 uranium rods, a total weight of 5 tonnes. Alternative and additional lattice configurations can be supplied. Two stainless steel tanks can be supplied; the first fits closely around the lattice assembly for studies on unreflected systems, the second is a larger tank to provide a water reflector. Plastic covers prevent the ingress of dust. A platform around the tank enables the operator to insert monitoring and counting equipment into the lattice. A special traversing mechanism accurately positions measuring foils and detectors. This mechanism operates along three axes and covers the whole system.

Nuclear Chicago Model 9,000

THE Nuclear Chicago Model 9,000 is a water moderated, natural uranium assembly designed for nuclear engineering courses at colleges and universities. The Model 9,000, which is supplied in packaged form, costs in the region of £8,000. A range of accessories is also available.

A stainless steel tank, 4 ft in diameter by 5 ft high, contains 435 gal of water which acts as a moderator and shield. Immersed in the water there is a lattice-like arrangement of 271 vertical aluminium tubes held in place by two grid plates located near the bottom of the tank. Each tube contains five aluminium-jacketed natural uranium rods approximately 8-in. long by 1-in. in diameter. A neutron source such as plutonium mixed with beryllium is placed at the centre of the uranium lattice to initiate and maintain the chain reaction. The fission process in the assembly results in a multiplication of the neutron flux from the source by a factor of six to seven.

The open construction of the Model 9,000 provides easy access to its internal parts for experimentation and instruction. The lattice configuration, the uranium rods, and even the neutron source position can be changed by instructor or students.

Included with the Model 9,000 there is a plastic dust and safety cover for the tank, a deionizer system for maintaining water purity, source tongs and source rod tool for loading and removing neutron sources from the reactor, and a tube lifter for inserting and removing the aluminium tubes containing the uranium.

(Nuclear Chicago Corporation, 333 East Howard Street, Des Plaines, Illinois. U.K. Agent: Continental Distributors, Ltd., 121 Earls Court Road, London, S.W.5.)

NUCLEAR CHICAGO SUB-CRITICAL ASSEMBLY, MODEL 9,000—SPECIFICATION

Lattice: Two grid plates hold and position 271 aluminium tubes arranged in a hexagonal pattern. Wall thickness of tubes—0.035 in. Tubes designed to hold natural uranium slugs available under the AEC assistance programme. Total weight of natural uranium—5,500 lb.

Lattice core: Hexagonal, 42.1 in. high, 35 in. maximum diameter.

Moderator: Light water, 3,600 lb, 435 gal. Deionizer supplied to maintain purity.

Reflector: Light water. Minimum thickness 7.35 in.; maximum thickness, 8.43 in. Essentially an infinite reflector thickness since migration length of neutrons in ordinary water is less than 2.5 in.

k_{inf}: 0.960.

k_{eff}: 0.842.

Neutron Amplification: 6.0—7.0.

Flux: Central region flux using five one-curie plutonium-beryllium sources is approximately 5×10^4 n/cm² per second.

Reactor Vessel: Cylindrical, 60 in. high, 48 in. diameter. Stainless steel, split into two sections 30 in. high by 48 in. diameter with watertight flange.

Weight: Completely assembled with uranium and water—10,800 lb.

Floor Loading: Reactor supplied with load bearing base, which can be used on ground-level normal concrete floors. (Model LDB-2 load distribution base is available for above ground installations).

Ceiling Height: Minimum ceiling height of 10 ft. is recommended.

Neutron Sources: Plutonium-beryllium sources are loaned by Mound Laboratories of U.S. AEC. They have a long half-life (24,000 years) and emit less than 0.7 gamma for one neutron. The AEC will consider supplying up to 5 curies of plutonium-beryllium. The source is supplied in one curie sizes 1.02 in. in diameter by 1.3 in. high. Radium-beryllium and polonium-beryllium sources are also available.

Nuclear Chicago's Model 9,000. Above the honeycomb lattice there is an automatic traversing mechanism for horizontal and vertical positioning of a neutron sensitive detector. The lattice configuration can be easily changed by students.

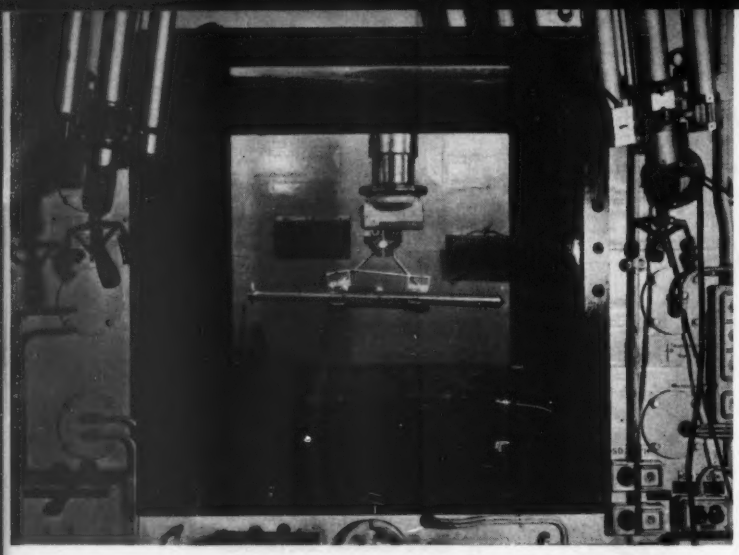


Fig. 1.—Calder fuel element under examination at Windscale.

Changes in Calder Fuel Elements under Irradiation

By Dr. V. W. ELDRED, M.A., Ph.D., A.I.M.,
A. STUTTARD, A.I.M., and
J. SKINNER, B.Sc.(Eng.) (Met.)
(R. and D. Branch Laboratories, D. and E. Group, U.K. AEA Windscale)

BY April, 1959, the first power-producing reactor[1] at Calder Hall, Cumberland, had been operating successfully for 2½ years and a further three identical reactors had been commissioned on the same site. During that period over 70,000 fuel elements were charged into the reactors. The behaviour of these elements under irradiation has been the subject of very close scrutiny by the Research and Development Branch of the U.K. Atomic Energy Authority and over 1,000 selected elements have been discharged for experimental investigation in the laboratories at Windscale[2], adjacent to Calder Hall. In this way, it has been possible to follow the changes occurring under irradiation and to obtain valuable information relevant to the design and choice of materials for fuel elements intended for the larger power stations, based originally on the Calder Hall design, now under construction by British companies.

An essential requirement of a satisfactory fuel element is that the can should remain leak-tight throughout its life in the reactor, thus preventing oxidation of the fuel and release of activity into the system. Particular attention has therefore been paid to the small number of elements discharged from the Calder Hall reactors because of suspected leaks. As the most obvious way in which an element may fail in service is through straining of the can by dimensional changes in the fuel, considerable effort has also been devoted to careful measurements on a large number of elements with the aim of detecting at an early stage any trends that might lead to deleterious effects at higher irradiation levels. This article will therefore be devoted mainly to two aspects of the behaviour of Calder Hall fuel elements: the confirmed failures will be described, and data on dimensional changes occurring under irradiation, in one particular variety of fuel, will be reported and discussed. Although the element itself has already been described in some detail[2, 3] it will be appropriate here to summarize its principal features before describing the techniques employed for its examination after irradiation.

The Calder Hall Fuel Element

The fuel is natural uranium metal in the form of cylindrical rods 101.6 cm long and 2.92 cm in diameter, traverse-quenched[2] to produce a fine grain size. Shallow circumferential anti-ratcheting grooves, of rectangular cross-section, are machined at intervals along the bar to assist in locking the bar and can together.

The alloy used for the can is known as Magnox A12 and is composed essentially of magnesium with 0.5-1.0% aluminium and 0.002-0.050% beryllium. The fins, which are 11.4 mm high and 0.6 mm thick, constitute a continuous helical spiral of 3.2 mm pitch; between the fins the wall thickness of the can is 1.6 mm except in the region of the end-caps where it is increased. Both ends of the can are sealed by end-caps edge-welded to the main can wall; the base of each end-cap is separated from the ends of the uranium bar by a disc of magnesium alloy harder than Magnox A12. Before the second weld is made, helium is introduced into the can to act as a tracer gas in subsequent leak testing. The can is forced into intimate contact with the bar by subjecting it to an external pressure of carbon dioxide at about 500°C.

Before an element is loaded into the reactor, conical end-fittings are screwed on and a brace, consisting of three longitudinal struts, is attached to the fins. It has been shown that the brace, by coming into contact with the channel wall during irradiation, is very effective in preventing excessive bowing of the element.

Six fuel elements are loaded into each vertical channel in the graphite moderator, the metal cone at the bottom of one element seating in the end-fitting at the top of the element below. The carbon dioxide coolant passes upwards around the elements so that the element at the bottom of the stack (No. 1) operates at the lowest can temperature (~200°C). The No. 3 element is subjected to the highest flux, but the highest fuel temperature (500°C) and can temperature (400°C) occur in channel positions 4 and 5 respectively.

The presence of radioactive fission products in a channel is revealed by the burst cartridge detection gear[1]. A signal that is significantly above background is taken to indicate a leaky fuel element and the entire channel concerned is

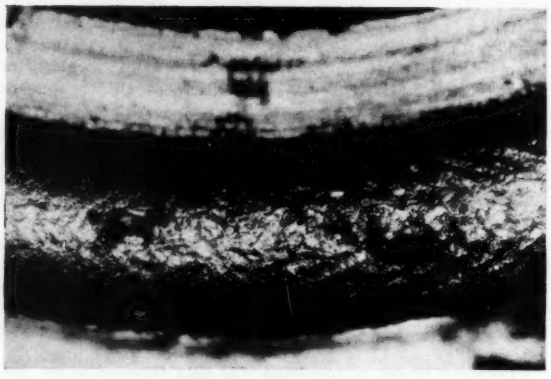


Fig. 2.—Fine crack in weld responsible for fuel element failure.

discharged for laboratory examination. Since the signal gives no indication of which element in the channel is defective, all six elements must be examined and tested.

Method of Examination

After discharge, elements are generally stored for at least a week until their activity has decreased to an acceptable level. Whenever possible, they are stored in dry coffins; alternatively, they are kept under water and some corrosion of the Magnox occurs.

Each element is visually inspected through one of the four zinc bromide windows (Fig. 1) of the fuel element examination cave[4]. The element is then X-rayed, in at least six different positions, to obtain shadow-graphs of the fuel. If the element has failed in service, oxidation of the uranium may be detected at this stage. The amount of oxide present will depend on the operating temperature of the element and the length of time for which it was in the reactor after a leak developed: on high-temperature elements clearly visible bulges of oxide may form, but on elements from No. 1 channel position oxide is not generally detectable on the radiographs. The extent of bowing in each element is determined by measurement on the radiographs.

When the element concerned is from a channel discharged because of a signal on the burst cartridge detection gear, it is leak tested. In the past the examinations have been seriously restricted by lack of suitable facilities for this purpose, but leak-testing is now regarded as a most important stage in the post-irradiation examination of an element and several different techniques suitable for remote operation have been investigated and are under development. At the present time, the tests in the cave are carried out in two stages, referred to respectively as leak detection and leak location: both employ nitrous oxide as a tracer gas. In the leak detection test the element is pressurized externally with nitrous oxide, which enters the can through any leaks, and is then transferred to a sampling tube where any gas escaping from a leak is detected by means of an infra-red gas analyser.

If a leak is detected, a connection is made to the element so that it can be pressurized internally with nitrous oxide and the site of the leak positively located by scanning the outside of the can; subsequent metallographic examination may then be concentrated in that area.

The next stage is to separate the can from the fuel. Transverse cuts are made through the can at each end to remove the end-caps and welds. When three full-length longitudinal cuts have been made in the can it can then be separated from the bar. Finally, the welds and lengths of can are posted out of the cave for inspection, vacuum testing and metallographic examination. A thin film of uranium oxide on the inside of a can provides confirmation that the element had failed in service. The bar is measured, and its density determined, before being sectioned to provide specimens for metallographic examination[4, 5] and mechanical testing. Except for the removal of the end-caps, all the cutting operations take place under water.

TABLE 1
Confirmed Fuel Element Failures in the Four Calder Hall Reactors to April 30, 1959

Failure Identification No.	Mean Channel Irradiation at Discharge (MWd/t)	Channel Position of Failure	Type of Uranium*	Cause of Failure
1	6	3	Ca	Leak in weld due to a manufacturing defect or handling damage.
2	8	5	Mg	
3	16	5	Mg	
4	18	2	Mg	
5	30	3	Mg	
6	48	5	Mg	
7	133	1	Ca	
8	134	4	Ca	
9	220	4	Ca	
10	25	5	Mg	Incompatible wire (thermocouple cartridge).
11	1	6	Mg	Cause of failure not positively established. Probably manufacturing defects in can wall of 11 and 12.
12	21	5	Mg	
13	404	6	Ca	
14	94	2	Mg	Development of a grain-boundary leak path through the can wall during irradiation.
15	357	1	Ca	
16	417	1	Ca	
17	470	1	Ca	
18	478	1	Ca	
19	493	1	Ca	
20	511	1	Mg	
21	512	1	Ca	
22	575	1	Ca	
23	619	1	Ca	
24	637	1	Ca	
25	735	1	Ca	

* Ca: calcium-reduced uranium.
Mg: magnesium-reduced uranium.

Fuel Element Failures

The post-irradiation examination has revealed a fuel element failure in 25 channels. In Table 1 the defective elements are listed and divided into four groups according to the probable cause of failure.

Leaky welds were found in nine elements (failures 1-9) that had given signals at low irradiation levels. Welds in four of the elements had apparently been damaged when the elements were being loaded into the reactor. The site of the leak in another was a very inconspicuous fine crack (Fig. 2); on sectioning, this was found to be associated with a blow-hole (Fig. 3). In two cases leaks were associated with larger blow-holes, clearly visible on the surface of the weld; their acceptance at the inspection stage of manufacture appears to have been an oversight. Cracks found in two other welds were probably also manufacturing defects. The failure of this group of nine elements was clearly due to inferior welds or welds weakened by mechanical damage during handling.

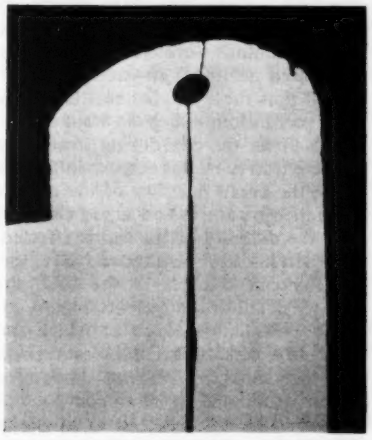


Fig. 3. — Cross-section through weld crack showing blow-hole and leak path.

A thermocouple cartridge (failure 10) failed because a galvanized iron wire was accidentally used instead of the normal stainless steel wire to hold the thermocouple leads in position on the can.

In three elements (failures 11-13) the cause of failure was not established with certainty, owing to the confusing effects of corrosion during under-water storage in one case and to accidental mechanical damage after irradiation in the other two.

The largest group of failures (14-25), generally occurred at higher irradiation levels, and had quite different characteristics. All but one of the elements concerned were

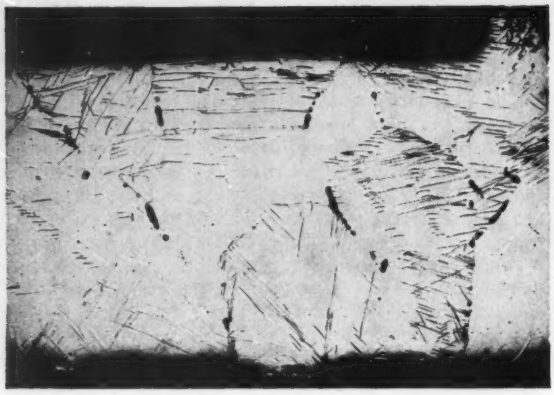


Fig. 4.—Grain boundary cavities in the can wall of a fuel element failure.

from channel position 1 where the temperature is lowest. No defects were discovered in the end-cap welds, but when the cans were metallographically examined rows of small cavities (Fig. 4) could be seen at some of the grain boundaries in the can wall and grain-boundary cracks had formed, probably by the joining up of cavities, in some localities. Grain-boundary effects of this sort are well known[6] in many metals and alloys subjected to creep rates of strain and were seen in prototype Calder elements irradiated at 100°C in the Windscale piles[7]. There is no doubt that these 12 elements failed by the development of leak paths along the grain boundaries as a result of strains imposed on the can during irradiation. A given strain is more effective in this respect in the lowest channel position since the creep ductility of the can is comparatively small at the temperatures concerned (200°C); there is no evidence that the ductility of the can is affected by irradiation itself. The strains are believed to have arisen primarily from dimensional changes in the fuel; these are discussed in greater detail in the next section.

The irradiation levels at which these failures occurred covered a wide range, and it is important to appreciate that for each defective element discharged many hundreds of others, irradiated under similar conditions, have been taken to the same or higher irradiation levels without failure. This indicates that some elements are markedly different in quality from the rest and suggests that if the reasons for the differences can be understood, it may be possible to eliminate the undesirable elements, without any major changes in the materials, by further quality control or physical testing in the production line.

Regarding the failures as a whole, it is particularly interesting to note that, apart from those occurring at an early stage in the irradiation history of a charge and due mainly to manufacturing defects or mechanical damage, there have been no failures in the high-temperature channel positions.

Dimensional Changes in the Fuel

The overall length of an irradiated element is normally measured between flats and a small correction is applied to allow for any bowing (determined from the radiographs) that has occurred. As the ends of an irradiated bar often show very slight concavity, the length actually measured is effectively that of the cylindrical surface in contact with the can.

Uranium metal of two types has been used in Calder Hall elements. In many of the earliest elements uranium produced by calcium reduction of the hexafluoride was used, but this was soon superseded by the purer magnesium-reduced material. Although current production is all magnesium-reduced, the time cycle between a change in manufacturing method and the discharge of elements for measurement after reasonably high doses is such that the volume of results on the magnesium-reduced material is limited and the detailed data reported here will be confined to the calcium-reduced bars.

The changes in length that occurred in selected bars of calcium-reduced uranium, irradiated to 1,150 MWd/t or less, are plotted against irradiation level, for each channel position, in Figs. 5-7. The maximum error in the percentage change in length for a given bar is estimated at ± 0.05.

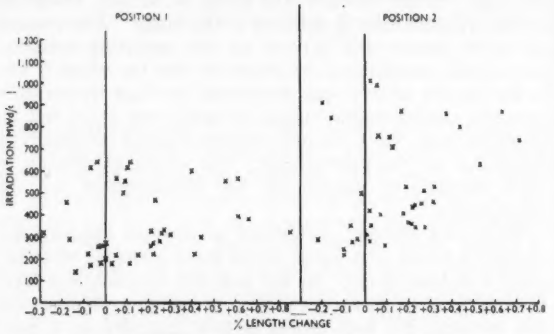


Fig. 5.—Length changes in bars of calcium reduced uranium irradiated in channel positions 1 and 2.

From Figs. 5-7 it can be seen that the change in overall length was less than 0.5% in all but eight of the 220 bars measured. Above 500 MWd/t the bars generally increased in length; but at lower irradiation levels significant

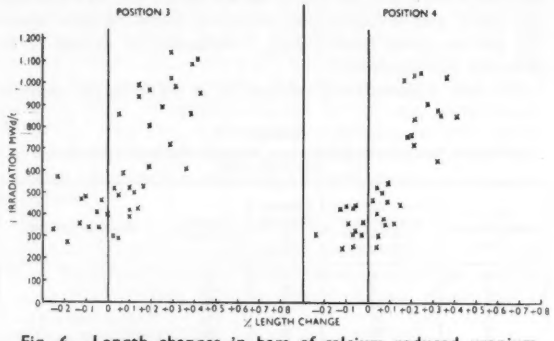


Fig. 6.—Length changes in bars of calcium reduced uranium irradiated in channel positions 3 and 4.

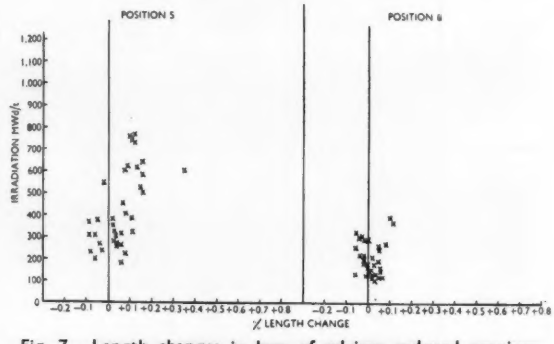


Fig. 7.—Length changes in bars of calcium reduced uranium irradiated in channel positions 5 and 6.

decreases in length occurred in some cases. There is considerable scatter in the results, outside the error of measurement, in all positions, especially for those elements at the bottom of the stack (channel positions 1 and 2).

The changes detected are believed to be the resultant of three principal effects:—

(I) *Volume Changes*

When the change in density on irradiation is plotted against irradiation level, a very similar trend is detected in all channel positions (i.e., there appears to be little temperature sensitivity within the range concerned). Fig. 8 shows the results obtained at the highest fuel temperatures (channel position 4). A curious feature is the negligible swelling detected in the first 500 MWd/t. In the range 500-1,000 MWd/t the density decreases by approximately

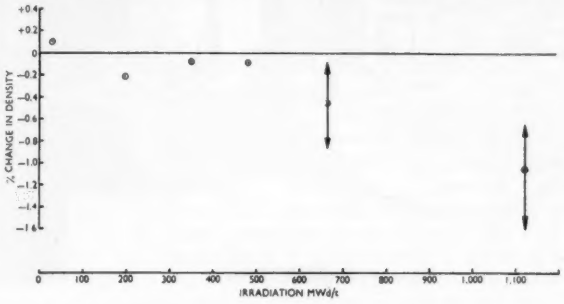


Fig. 8.—Density changes in Calder bars irradiated in channel position 4. Each point is the mean of measurements on at least 5 bars. The full range of the results at the higher irradiation levels is shown.

1%, corresponding to an increase in length of about 0.3% if the dimensional changes are homogeneous. In channel position 4 (Fig. 6) the dimensional changes are attributed mainly to this change in density.

(II) *Irradiation Creep*

Under the compressive load of the elements above an element will tend to shorten by irradiation creep[8], especially at the lower temperatures. An estimate of the creep rate in each channel position can be obtained from bowing measurements. Approximate values for the six channel positions in the Calder Hall reactors are as follows:—

Channel Position	Creep Rate (Elastic Deflections/MWd/t)
6	0.4
5	< 0.1
4	< 0.1
3	0.4
2	0.6
1	0.4

Thus in No. 2 channel position, where the effective load on the bar is 50 kg and an elastic deflection corresponds to a shortening of 0.005 mm (taking Young's Modulus as 1.61×10^6 kg/cm^2), a decrease in length of 0.3% would be expected by 1,000 MWd/t if no other effects intervened.

(III) *Irradiation Growth*

The scatter in the observed length changes in a given channel position is partly attributable to experimental error, temperature differences and real variations between elements in creep rates and swelling behaviour. But the fact that the most marked increases in length and the widest spread in results were in channel positions 1 and 2, where the fuel temperatures were lowest, suggests that irradiation growth, which is known[7, 9] to be greater at 200°C than at higher temperatures, was also partly responsible for the effects observed. It is therefore inferred that a very small degree of preferred orientation, leading to overall elongation by irradiation growth, may have been present in some of the bars measured.

The length changes observed in these bars are so small in relation to the available creep ductility of the can that no failures due to overall straining of the can would be expected. In fact, the length changes that had occurred in failures 14-25 (Table 1) were not amongst the largest for these channel positions. Recent work has shown, however, that in some bars the strains are not uniform along the length and may locally be much greater than the overall strain in the bar. The fuel element failures attributed to irradiation effects are believed to have contained bars of this type. Some support for this explanation is provided by the fact that a significant proportion of the bars concerned had been straightened by an unusually severe reeling operation in the course of which localized deformation of the bar had occurred; it is probable that the cold working involved introduced an additional degree of preferred orientation and led to more severe irradiation growth in the regions concerned.

Discussion and Conclusions

The 25 confirmed fuel element failures represent 0.04% of the elements charged. Although failures due to manufacturing defects and mechanical damage (0.02%) serve to emphasize the extraordinarily high standards of inspection and handling required in fuel element manufacture, the main interest naturally lies in those elements which failed by irradiation effects. So far as the operation of the Calder reactors is concerned these failures have not been a cause of embarrassment but it is desirable that they should be understood and prevented in fuel elements designed to withstand higher burn-ups.

The observations described show quite clearly that, in this type of element, failure due to irradiation is more likely to occur in elements operating at the lowest temperature, where the ductility of the can is least and the fuel is most susceptible to irradiation growth. As a result, a very considerable effort has been directed by the U.K. AEA towards a study of the factors controlling the low-temperature stability of the fuel and the ductility of the can. It has been shown, for example, that the tendency of a Magnox A12 can to develop grain-boundary leak paths at creep rates of strain can be very markedly reduced by improving its metallurgical condition.

Another important consequence of this type of work is the appreciation that results of the utmost value can be obtained from the careful examination of irradiated elements, and elaborate new facilities are now under construction at Windscale to enable similar studies to be made on a representative selection of irradiated elements from the new power stations in 1961 and afterwards.

Acknowledgments

The examination of irradiated fuel elements is essentially team work and the authors acknowledge with gratitude the hard work and co-operation of their colleagues. The paper is presented with the permission of Sir William Cook, managing director of the Development and Engineering Group, and Dr. H. Kronberger, director of Research and Development, U.K. AEA.

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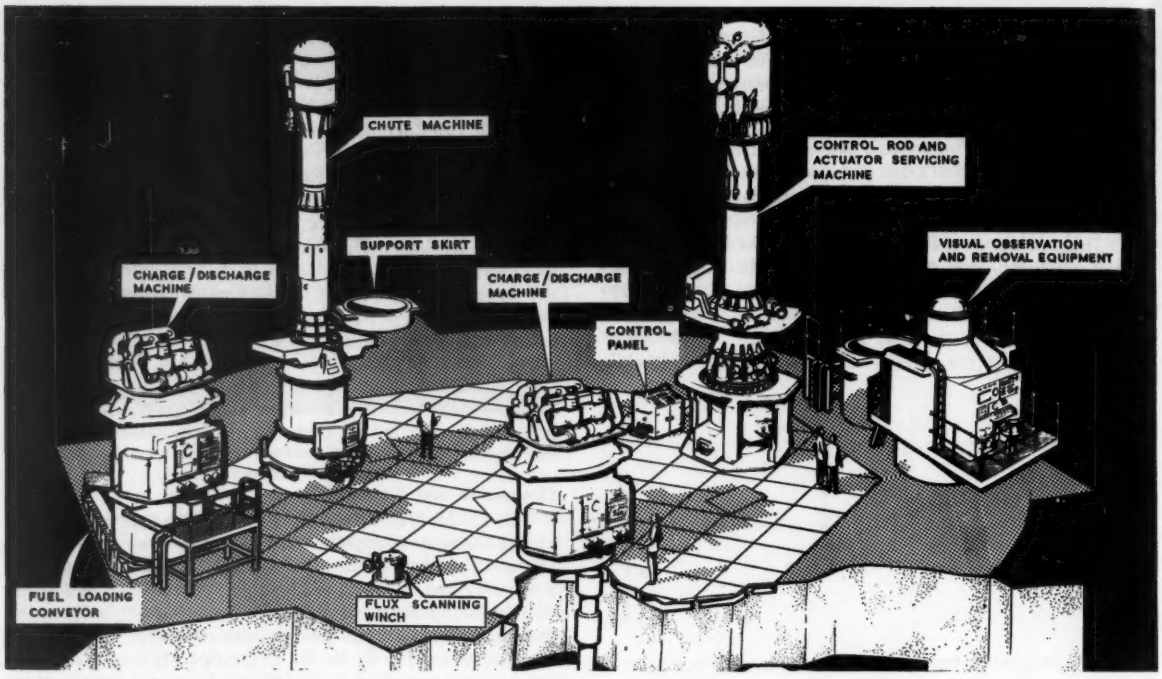


The charge face for a Berkeley reactor; the majority of the fuel handling equipment is being made by John Thompson Ordnance

Fuel Handling at Berkeley

Fabrication of the machinery for on-load fuel changing is well advanced: preliminary testing is now in progress at the Wolverhampton works of John Thompson Ordnance.

THE manufacture of nuclear fuel handling equipment for "on-load" operation calls for a considerable amount of fabrication to close tolerances: precision machining of a very high order is essential to ensure accurate positioning of the equipment over the standpipes.

The majority of the fuel-handling plant for Berkeley has been the responsibility of John Thompson Ordnance—a company with a wide experience of precision engineering and the development of special-purpose machines. Indeed, many of the company's machine tools have been specifically engineered for precision work and the factory itself—part of the John Thompson industrial estate at Wolverhampton—is arranged to ensure a high standard of cleanliness on the shop floor together with constant atmospheric conditions.

For the past three years much of the production capacity of the Ordnance company has been absorbed by the making of the fuel-handling machinery for the two Berkeley reactors. From both the design and production point of view, much of this work has been of a pioneer nature: Berkeley will be one of the first nuclear power stations where all fuel changing operations will be carried out with the reactors under load.

In addition to being completely heat resistant and capable of operating in pressurized CO_2 much of the machinery must not only withstand severe gamma radiation but at the same time offer protection from neutrons for the charge face operators both when equipment is coupled to the standpipe and when irradiated elements are being discharged.

The choice of materials for making the machinery and the stringent production requirements created problems which were surmounted only by extensive research and experiment. All materials must be compatible and in this direction difficulties were encountered with such items as rotating bearings, etc. Furthermore, in welding the assemblies, the different creep rates of stainless steel and mild steel had to be taken into account. Because of its inaccessibility during use and its subsequent contamination the remote handling equipment cannot be manually maintained and it must, therefore, be completely reliable in operation.

The general conception of fuel handling at Berkeley is that each major operation is handled by a separate machine—making a total of 5 or 6 specialized units on the charge face rather than 1 or 2 multi-purpose fuel-handling devices.

On each reactor charge face, therefore, one might expect to see:

(a) Two charge/discharge machines (a third machine is kept as a spare).

(b) One chute machine with shielding (another bare unit as spare).

(c) One control-rod and actuator servicing machine (CRASM).

(d) One visual observation and removal equipment (VORE).

(e) A series of different support skirts for use with the above machines.

(f) A variety of ancillary units such as a fork-mast crane (100-ton capacity), floor-plate removal trolley, gas purge trolley, control panel and so on.

The use of several specialized units as opposed to a multi-purpose machine obviously provides scope for discussion. On the one hand although cumbersome in operation (standpipes must be unsealed and resealed each time a machine is placed into position or removed) the Berkeley equipment provides a greater flexibility and there is less risk of a major delay should a particular unit fail in service.

On the other hand one could argue that a multi-purpose device should show a saving in manpower and in ease of operation. The complexity of design, however, might well outweigh the technical advantages and a cautious designer considering this problem four years ago (when Berkeley was originally designed) would undoubtedly have chosen the specialized unit approach as the safest method in view of the lack of experience of " on-load " nuclear fuel changes.

Before describing the Berkeley equipment in detail, a brief review of the operating conditions would not be out of place. Each graphite core contains some 3,000 fuel channels, groups of 64 channels each being served by a standpipe positioned immediately above the pressure vessel. Each channel contains 13 fuel elements, a reflector and a dummy element or gag.

The charge face floor—set in the thick concrete biological shield above the reactor pressure vessel—is protected by heavy thick steel plates each of which covers a group of three control rod actuator standpipes and one fuel charge/discharge standpipe. Before a fuel charge can be effected, therefore, it is necessary to carry out the following operations:

(a) Remove floor plate.

(b) Position support skirt.

(c) Position chute machine, purge and pressurize, unseal standpipe, drop chute into reactor, reseal standpipe and remove chute machine.

(d) Position discharge machine, purge and pressurize, unseal standpipe, remove contents of channel (one element at a time), reseal standpipe, remove charge machine. Discharge elements.

(e) Position charge machine, purge and pressurize, unseal standpipe, charge channel (one element at a time), reseal standpipe, remove charge machine.

(f) Position chute machine, purge and pressurize, unseal standpipe, remove chute, reseal standpipe, replace chute machine on parking skirt.

(g) Replace floor plate.

Support Skirts

With the exception of the CRASM skirt, which itself is a pressure vessel and a machine, all skirts are, basically, support structures. Semi-permanent support skirts for the loading conveyor; for the discharge well; and for both low and high parking, are provided for each reactor, which also has three movable operational skirts. The design of support skirts varies only in shielding requirements and overall height.

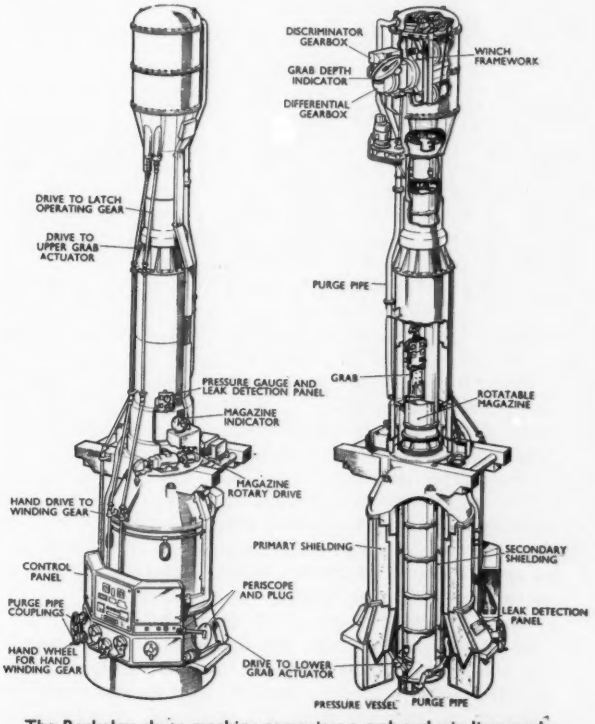
Operational Skirt: This is positioned where required on the charge face floor and can accept any machine. Some 16¼ in. of borated polythene chips in oil and 10 in. of lead are contained in its walls and the unit is 2 ft. 6 in. high. Header tanks, connected to the polythene-filled ring, accommodate the expansion or contraction of the polythene mixture under extremes of temperature. Air release plugs are screwed to the top of the skirt for manufacturing purposes and pads, at the base, allow the attachment of dowel brackets for location over the inspection well, etc. Friction pads on the base prevent movement while the skirt is resting on the floor and extra shielding, in the form of borated hydroboard enclosed in fabricated plating, extends outside the bottom of the ring.

Part of this material is hinged to allow the engagement of the crane forks with the lifting lugs. It must be replaced, level, after the crane has disengaged. Extra sections are positioned on the floor to make up a roughly square mat of shielding after the skirt has been positioned. Safety rails are included for protection when lining-up and lowering the skirt. The two dowel pin holes on the top of the skirt, in which the pins on the machine engage to give correct alignment, can be adjusted in the horizontal plane. They comprise tubes with slippers in external horizontal guides in fabricated housings. Tangentially, each tube can be moved independently by a screw jack, driven by a Teleflex cable and handwheel; radially, one tube is caused to move by a locally hand-operated screw jack, while the other is restrained to move with it only by the optical alignment ring.

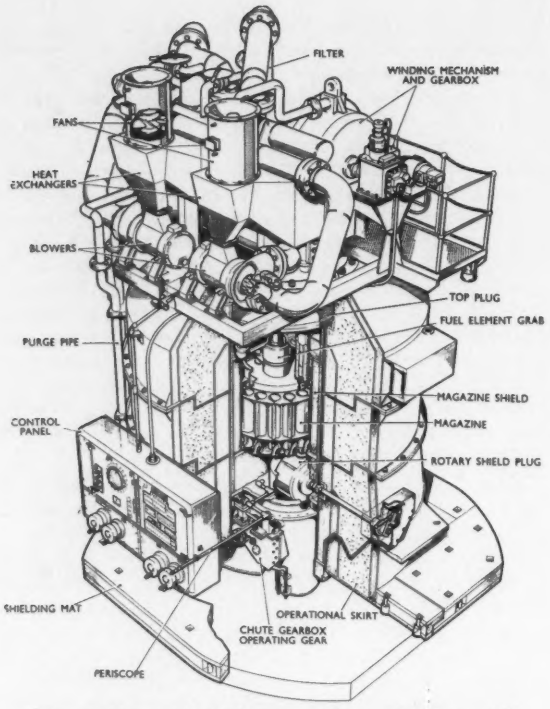
Loading Conveyor Skirt: This is semi-permanently positioned over the loading conveyor to locate and support the charge machine when it is being refilled. It is 5 ft 3 in. high and contains 15¼ in. of iron shot concrete in its walls. A separate platform on the outside gives access to the machine's controls.

Discharge Well Skirt: Semi-permanently positioned over the discharge well and the adjacent chute decontamination hole, this skirt locates and supports the discharge machine, the chute machine, the visual observation and recovery equipment (VORE), and the CRASM magazine for discharging. The skirt is 2 ft. 6 in. high and contains 4 in. of lead and 19¼ in. of iron shot concrete in its walls.

Low Parking Skirt: This unit is semi-permanently positioned near the entrance to the maintenance bay. It is 2 ft 6 in. high, but its walls have no shielding.



The Berkeley chute machine comprises a grab and winding mechanism together with a three-chambered chute storage magazine.



The charge and discharge machine together with operational skirt and shielding mat. The magazine has twenty chambers; there is full provision for removing heat from irradiated elements.

High Parking Skirt: Semi-permanently positioned close to the low parking skirt, this unit can accept any machine. It is 7 ft $1\frac{1}{4}$ in. high and its walls contain 8 in. of lead and $11\frac{7}{8}$ in. of iron shot concrete. Inside it are guides which enable the crane to position the skirt as required.

Chute Machine

The chute machine is the means whereby various chutes can be placed in the reactor to bridge the gap between charge face floor and the reactor pile. The machine handles the following units: Charge chute for use with the charge/discharge machine: flux scanning chute used in conjunction with the flux scanning winch; fixed absorber chute used with the CRASM machine; thermocouple chute to work with its own winch vessel; reactor periscope; standpipe plug which normally closes and shields the bore through the charge standpipe; metal samples handling chute; graphite sample trailing thermocouple chute; and charge standpipe sealing plug.

There are two chute machines for each reactor charge face; the spare replacement unit does not have shielding. Because the chute machine operates with the reactor on load, it includes a pressure vessel which can be connected to the reactor via the standpipe.

The chute machine's equipment comprises a grab and winding mechanism to raise or lower the chutes; a rotating three-chambered magazine to store two chutes; mechanism to cause the grab to connect with or release its load, and to support a released load in the magazine.

This equipment is contained inside the pressure vessel and on the outside there are gearboxes, etc., to operate the equipment and to open or close the standpipe valve. A valve at the foot of the machine seals the gas inside the machine on removal from the standpipe. Facilities are provided for purging and pressurizing the machine.

Outside the main shielding on which the pressure vessel is supported, there is a control panel for operating the machine. The chute machine is placed by the crane on an operational skirt when working over a charge point, over the inspection well, the discharge well, or the decontamination well. With the exceptions of the high parking skirt and the loading skirt, the machine can be placed on any support skirt. Electrical interlocks prevent lifting until machine and standpipe have been correctly prepared. Interlocks, all of which operate "fail safe," also prevent incorrect operation of the machine.

Charge and Discharge Machines

The main constituents of these machines are fuel element grab, grab winding mechanism, and control switches, winding gearbox assembly, drives to magazine and latch mechanism, chute gearbox and standpipe operating gear, control panel and its mechanism, and circulating and cooling equipment. Basically, the charge/discharge machine is a winding mechanism controlling a grab which can engage or disengage from a fuel element, etc., as required. The rotatable indexing magazine is capable of accommodating 13 fuel elements, a reflector, a gag and and a spare, and four concrete plugs which seal the chute. Below and above the magazine there are shield plugs to reduce the effect of radiation; in the lower plug there is a rotary shield to seal-off the channel used by the grab.

A unit comprising a gearbox, etc., to connect with and able to control the fuel element chute when it is in the reactor, is positioned at the bottom of the machine. All of this machinery is contained in a pressure vessel, shielded on the outer side to give the necessary protection, and built to withstand the working pressure in the reactor.

For operating the machinery, drives (power and hand), electric indicator wiring, etc., pass through the pressure vessel and shielding to a control panel in which routine operations can be automatically controlled by means of relays, uni-selector switches and a selective card system. A fully comprehensive system of interlocks (both mechanical and electrical) prevent actions which may cause damage or prove dangerous.

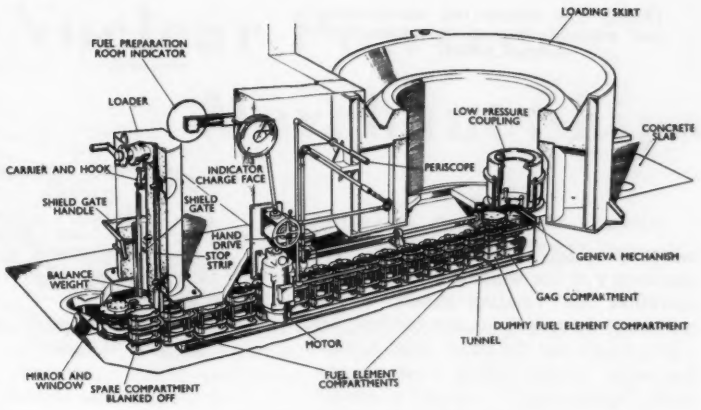
The charge/discharge machine can be used to discharge elements from the reactor into its magazine and from there, down the discharge well to the disposal flask. In such circumstances it is a discharge machine; internally, it may be highly contaminated and is not normally used for any other purpose. The machine is used as a charging machine when it charges its magazine with new fuel elements from the loading conveyor and afterwards charges, from its magazine, an empty reactor channel.

To operate, a machine must rest on a skirt; the loading conveyor skirt, the discharge well skirt, or an operating skirt. When not operating, the machine rests on a parking skirt. Basically, all skirts are similar, exceptions being in shielding properties and height. The charge/discharge machine, weighing approximately 100 tons, must be lifted by crane from one skirt to another.

A circulating cleansing and cooling system, normally employing air but substituting CO_2 when connected to the reactor, is positioned on the top of a charge/discharge machine. When resting on the operating skirt, the machine is connected to the standpipe valve by a ring clamp. There are built-in facilities for opening or closing the flap valve to allow access to the reactor.

Each reactor has three charge/discharge machines; the charge and discharge units on the charge face for operational purposes, and a standby machine, kept in the maintenance workshops ready for service when required.

(Right) Fuel element loader and conveyor and associated loading skirt to which the charge machine is coupled before loading commences.



An interesting feature of the charge/discharge machines is the provision of an automatic sequencing control panel based on a punched card system. Three basic operations can be handled: Charging channels, discharging channels and unloading irradiated elements over the discharge well. Having decided which operation the machine is to perform, the operator selects one of three methods:—(a) entirely automatic (b) sequence by sequence or (c) maintenance. As one might expect all operations are fully interlocked, whichever type of control is in use.

Fuel Element Loader and Conveyor

This equipment is used for loading fuel elements into the charge machine and comprises loading skirt, low-pressure coupling, loading conveyor and its loader.

The conveyor consists of two horizontal endless chains passing around four sprocket wheels, each pair on a vertical axle. Supported between the chains there are 16 compartments of approximately the same section as the tube used in the charge machine magazine. Stops in the lower part of the compartment hold the fuel element which is lowered by the loader, and raised by the fuel element grab in the charge machine. The spacing of the compartments is such that they extend over half of the conveyor only: when the first is under the skirt, the last is under the loader. There are five spacers in the blank portion of the conveyor to maintain the correct spacing between the two chains. A motor with gearbox, mounted on the charge face wall, drives the conveyor.

Basically, the conveyor loader is a roller chain passing over a single sprocket wheel. In one end of the chain there is a carrier and hook and, in the other, a cylindrical balance weight. A handle turns the sprocket wheel via a spring-loaded clutch which prevents overload. To prevent the element, under its own weight, falling into the conveyor, this spring also loads a brake.

The loader casing is made up of one plain tube for the balance weight and another tube of the same sections as those in the charge machine magazine; the latter tube is cut away to allow a fuel element to be inserted. Two flat plates fill in the sides of the casing which is surrounded by iron shot concrete shielding in a steel retaining shell.

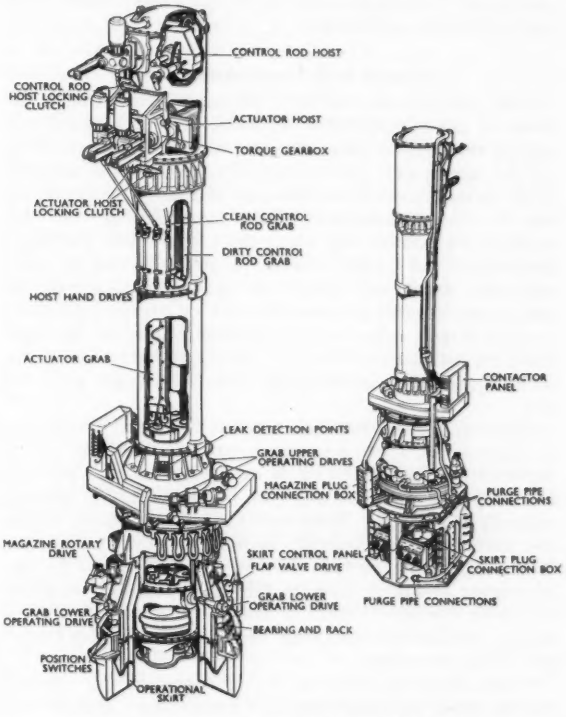
Control Rod and Actuator Servicing Machine

The control rod actuators are about 15 in. in diameter, 12 ft long (including shielding plug), and weigh 15 cwt. Secured in the biological shield in specially shaped standpipes, the actuators are in the pressure system. The screwed rings by which they are secured are turned by a motor and gear ring, known as the actuator clamping machine, which must be attached to the actuator during its removal or replacement in the standpipe.

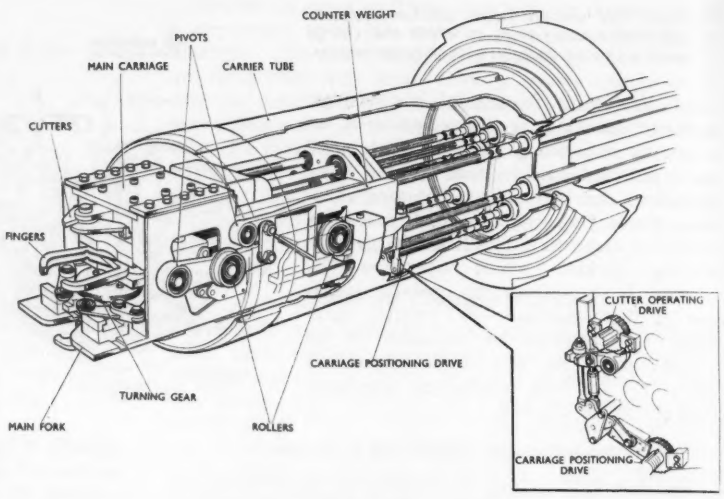
The CRASM is employed to exchange actuators and control rods, gags, fixed absorbers, etc., in the reactor, with spares. The complete unit comprises a magazine section containing grabs and their winding gear, and a support, or skirt section complete with various tools by means of which the actuator can be separated from or connected to its control rod. The skirt section is also used with the visual observation and recovery equipment when necessary. Both sections can withstand, either separately or together, the gas pressure in the reactor, and the operations of exchange, etc., can be performed while the reactor is on load.

About 40 ft high and 5 ft in diameter, the magazine section, together with its shielding, weighs 85 tons. It consists of a pressure vessel containing four magazines and associated equipment. Around the pressure vessel shielding is contained in a structure arranged so that the main crane can lift the complete unit. A ball bearing of 90-in. diameter on which the pressure vessel and the major portion of the shielding can be rotated in the vertical plane, is situated in the shielding structure.

Four magazines are contained in the pressure vessel: one for a clean (uncontaminated) actuator; one for a dirty (radioactive) actuator; one for a clean control rod; and one for a dirty control rod. Each magazine contains its appropriate grab which is raised or lowered by an



The control rod and actuator servicing machine services such items as actuators, control rods, gags, and fixed absorbers.



(Right) The control rod manipulating tool which is designed to operate with the CRASM.

independent set of winding gear. The operating gear for winding gears, for grab operation, for rotating shields in the bottom of the magazine, and for four flap valves which seal the vessel, pass through the vessel and shielding where appropriate. Operating gear is driven by electric motor and gearboxes on the outer surface.

Dimensions of the skirt section and its shielding are, approximately, 10½ ft diameter and 8 ft height, and the weight is 65 tons. The pressure vessel has two operating tools; the manipulating tool and the cable recovery tool. The former provides the means whereby the control rod is disconnected from or connected to the cable on the actuator, and the latter supplies a means of recovering the control rod and its cable, should an actuator become defective. To assist in these operations, there are two periscopes. A rotary shield and two flap valves seal against radiation and pressure, and a separate sleeve bridges the gap between the standpipe and the bottom of the skirt.

As a separate unit, the control panel is on a trolley connected by electric cables to the power supply and to both the magazine and skirt sections. When the visual operation and recovery equipment is in use with the skirt section, the control panel links the skirt and control panel on the recovery equipment.

Control Rod Manipulating Tool

This tool fits into the skirt pressure vessel through the lower of the flanged tubes for tools. It is horizontal and can be extended to move into the vertical line of the hoist on the standpipe. It is designed to enable the actuator cable to be disconnected from, or connected to, a control rod in all circumstances. The manipulating tool will support the control rod when these operations are being performed, but cannot release it until the rod is again otherwise supported. When the rod is supported on the tool, a gear turns it to the correct dis- or engaging position; crooked fingers seize the ball end fitting either on the cable from the actuator, or from the control rod grab, and move it, thus causing it to discharge from, or engage with, the rod.

Constituting an internal section contained inside the pressure vessel, a centre section to provide shielding, and an external portion consisting of control panel and gearbox assembly, the manipulating tool has seven drives passing through its gearbox. These drives are: To extend or retract the carriage of the internal section; to grip or clear the ball socket fitting; to turn the ball socket fitting to the dis- or engage position; to seize the cable ball-end; to move the cable ball-end vertically and horizontally to dis-, or engage the ball socket fitting; to position the cable cutter; and to cut the cable.

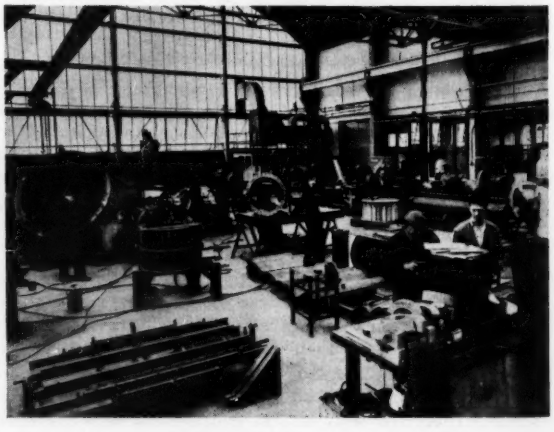
Three interlocks prevent the carriage of the internal section being retracted when it is supporting a control rod; prevent release of the ball socket fitting, unless the main body of the control rod is supported; and prevent the cutting of the cable unless the control rod is supported.

Visual Observation and Removal Equipment

Although no drawing is reproduced for the visual observation and recovery equipment (VORE), this unit is one of the most interesting items in the John Thompson Ordnance contract. VORE's purpose is to locate and remove any obstruction in the reactor channel. Basically the machine comprises a lifting gear and an indexing magazine similar to that of the charge/discharge machine so that irradiated debris can be handled safely.

The lifting gear is arranged to take a variety of different shaped grabs—current discussions suggest that up to a dozen different types of grab may be necessary in order to ensure that VORE can cope with any eventuality. In addition to these grabs the lifting gear will also control a closed circuit TV camera so that the operator can get some idea of the nature of the obstruction.

As mentioned in the introduction to this article, a particularly high standard of workmanship is called for in the manufacture of fuel handling machinery. John Thompson Ordnance have obviously made the best possible use of the company's experience in developing special purpose machinery. Future nuclear power stations will, however, call for a reduction in the number of machines on the charge face.



Part of the welding and fabrication bay at the John Thompson Ordnance factory at Wolverhampton.

The Safety of Nuclear Powered Merchant Ships

An analysis of the Recommendations recently put forward by the Ministry of Transport

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A COMMITTEE appointed by the Minister of Transport has recently put forward Recommendations for the Design and Construction of Nuclear Powered Merchant Ships.* These recommendations, which are reproduced on the following page, are intended for adoption as national Rules and also to serve as a basis for discussion at the forthcoming International Conference on the Safety of Life at Sea.

The Yarrow-Admiralty Research Department has been associated with the Recommendations in a double capacity: first in their formulation, since Y-A.R.D. representatives have taken part in the work of the Committee; and secondly in the early use of the draft Recommendations, during the examination by Y-A.R.D. of proposals for marine reactors put forward by various firms to the Galbraith Committee.

The Recommendations have been purposely made flexible to ensure that they do not unduly restrict the designer. Some interesting questions of interpretation therefore arise.

For instance, Recommendation No. 1 might at first sight be taken to prohibit the use of a reactor working on the direct cycle, i.e. without the use of intermediate heat exchangers, unless the main propulsion turbines themselves were sited within containment structure. However, reflection will show that the turbines could be outside the containment structure provided that:—

(i) The turbines are not normally operated on steam dangerously contaminated with fission products.

(ii) Isolating valves are provided in the steam and feed lines between the reactor and turbines.

(iii) The isolating valves are arranged to close automatically in certain prescribed circumstances, and rapidly enough to ensure closure before the steam in the engine room can become dangerously contaminated due to a fission product release within the reactor.

The wording of Recommendation No. 1 refers to the containment of the reactor coolant, but what do the words "reactor coolant" comprise? Naturally they include the fluid circulating through the primary circuit, but what about the various auxiliary loops, e.g. purification circuits, ion exchange columns, etc.? A working basis can be obtained by assuming that "the reactor coolant" encompasses all the fluid that is in some way connected to the primary circuit, and by assessing the need for enclosure within containment structure depending on:—

(i) Whether the coolant in question could conceivably become contaminated with fission products.

(ii) The pressure of the coolant.

The answer to (i) is usually "yes," but consideration of (ii) often shows many of the ancillary circuits to be at least partly at atmospheric pressure. If space within the containment structure is at a premium, it appears reasonable to assume that the ancillary circuits at atmospheric pressure need not be contained, although local shielding around certain components must, of course, be provided and each case must be judged individually on its merits.

While on the subject of containment, Recommendation No. 2 does not lay down specifically that the pressure to be withstood should be the instantaneous theoretical maximum pressure due to the escape of the fluids, but this is the interpretation that has generally been put on the wording. The maximum pressure will really be less than this, because it is impossible for all the fluids to be released instantaneously, particularly if flashing of high pressure water into steam is involved, and there will thus be heat loss to the steel work, etc., within the containment and to the containment structure itself before the maximum pressure is reached. The difference between theoretical and actual maximum pressures can be treated as a safety factor, although in certain cases it may be desirable and practicable to calculate the times involved and the heat transfers sufficiently accurately to take advantage of this in fixing the design pressure.

Recommendation No. 2 states that the pressure "shall be sustained without leakage in excess of an approved amount."

The approved amount, in any particular case, will depend in the main upon:—

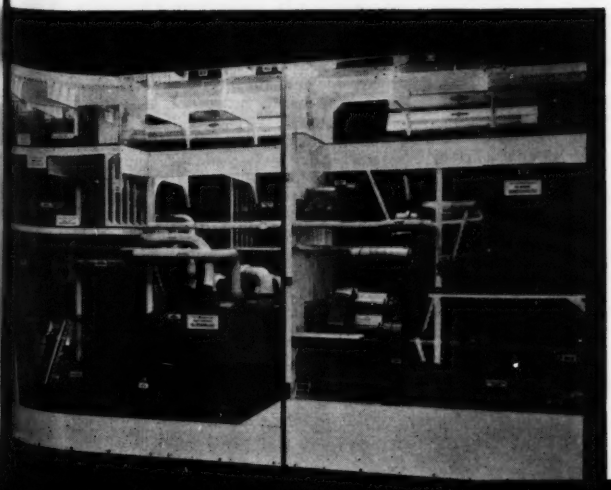
Whether the ship will be arranged to berth close to centres of population.

The limit of radioactive release under accident conditions laid down by the Health Physics Authorities.

At present it appears that, in any application, the allowable leakage will be extremely small, probably corresponding to less than 1% pressure loss per day. To achieve such a leak-tightness of a comparatively large containment structure (probably not less than 30 ft in diameter) presents a formidable problem, particularly when it is recalled that there are numerous penetrations of the

(Continued on page 171)

Model of propulsion machinery for a vessel powered by an AGR prepared by Y.-A.R.D. as part of their investigation. This machinery would also be suitable for use with a PWR, BWR or OMR.



* Ministry of Transport. Report of the Committee on the Safety of Nuclear Powered Merchant Ships, Cmd. 958. (H.M. Stationery Office; price 3s. 6d. net.)

Nuclear Ships

Proposed M.o.T. Rules for Design and Construction

THE following rules are intended to give effect to the principles of a framework within which nuclear ships may be designed and constructed to meet the necessary safety criteria. It is stressed that these proposed rules are supplementary to present Ministry of Transport requirements for conventionally propelled ships and also that they will be subject to amendment in the light of experience:—

(1) Machinery and pipe systems through which the reactor coolant passes and which might, in the event of a mechanical or nuclear accident, discharge fission products or other harmful materials shall be enclosed in a containment structure.

(2) The containment structure shall be capable of withstanding the pressure arising from the simultaneous escape into it of the reactor coolant and a specified quantity of other working fluid, and any consequential exothermic chemical reaction resulting therefrom. Such pressure shall be sustained without leakage in excess of an approved amount. The containment structure shall be protected against collapse arising from external sea-water pressure. The design must be such as to provide the maximum practicable protection against penetration of the containment structure by missiles generated in a reactor accident.

(3) Accesses to the containment space shall be so arranged as to ensure the integrity of the containment structure. (This might be achieved by the use of air locks with suitable interlocking devices.) Where it is necessary to ventilate containment spaces this shall be done by a suitable mechanical ventilation system. All ventilation openings in the containment structure shall be as small as practicable and shall be safeguarded to the satisfaction of the appropriate authorities.

(4) The containment structure shall, as far as practicable, be surrounded by spaces incorporating structural and other provisions so constructed and sited as to afford adequate protection against damage arising from accidents outside the reactor installation. The design of the structure shall take account of the possible need to salvage the reactor installation from a sunken ship.

(5) The containment space shall contain no inflammable materials other than those necessary for use in the reactor system.

(6) Reactor materials which are chemically reactive with air or water to a dangerous degree shall not be used unless it can be shown to the satisfaction of the authorities concerned that adequate safeguards are incorporated in the particular system.

(7) Facilities shall be provided to ensure that fires within and without the containment structure shall not cause such overheating of the containment structure as to endanger its strength or integrity or damage essential equipment within it. (This might be achieved by cofferdams and flooding or spraying arrangements.)

(8) The structure and supports for the reactor installation shall be designed so that all items are held in position irrespective of the attitude of the ship and any shock arising from any accident other than one involving high explosives.

(9) The machinery and reactor installation shall be designed to operate satisfactorily under all seagoing conditions of rolling, pitching, heaving and a permanent list of 20 degrees.

(10) Reactor cooling systems shall provide for the safe removal of decay heat from the reactor and shall prevent excessive temperature conditions under all foreseeable operational and accident conditions at all angles of heel and list up to 70 degrees. It must also be shown to the satisfaction of the appropriate authorities that with the ship in any attitude failure of all decay heat removal facilities will not result in penetration of the containment structure.

(11) All systems essential for the safe operation of the reactor installation shall be provided with such auxiliary or standby arrangements as may be required by the authorities concerned. Such main and auxiliary systems shall be so separated as to give maximum protection in the event of an accident.

(12) The reactor shut-down arrangements shall be capable of shutting down up to an angle of list of 90 degrees. In addition they shall operate automatically when the ship either becomes submerged or heels to an angle of 50 degrees. The arrangements shall be capable of keeping the reactor shut down irrespective of the attitude of the ship without limit under all foreseeable operational and accident conditions. Effective shut down shall not be impaired by structural distortion of a pressure vessel or core.

(13) All necessary controls and instrumentation shall be arranged to permit control of the reactor installation from outside the containment structure. In addition to, and remote from the normal reactor control room, an emergency shut-down position shall be provided from which the reactor can be shut down and its condition monitored.

(14) Reactor controls, protective devices and instrumentation shall be provided to the satisfaction of the appropriate authorites. In particular, all shall "fail to safety" and be incapable of hazarding the reactor by maloperation by personnel.

(15) Where limitations on the rate of change of reactor power unduly restrict the flexibility of propulsive power, arrangements shall be provided to ensure that under all normal operating conditions adequate propulsive power shall be available to maintain good manœuvring characteristics.

(16) The main and secondary shielding shall be designed to ensure that, when the reactor is either operating or shut down, no persons on board or in the vicinity of the ship shall be subject to radiation exposures in excess of the permissible levels laid down in currently accepted national or international recommendations. The shielding arrangements shall also be adequate to enable cargo to be carried in accordance with relevant regulations. The containment structure must be shielded to give personnel in the immediate vicinity adequate short-term protection against radiations from fission products which may have been deposited within the containment space as a result of a nuclear accident. Control rooms, external communication rooms, bridges and other spaces necessarily occupied after accidental contamination of the containment structure shall be so sited and/or shielded as to ensure compliance with such acceptable emergency tolerance levels as may be laid down by a competent authority.

(17) Radiation detection and monitoring systems shall give warning and, if necessary, take action in the event of any radiation exceeding a predetermined safe level.

(18) Arrangements shall be provided to ensure that de-fuelling, re-fuelling, servicing and maintenance can be carried out safely without unacceptable exposure of personnel to radiation and without hazardous release of fission products to the environment.

(19) Suitable storage for radioactive waste products shall be provided on board. Arrangements shall be made so that such material can be safely discharged from the ship into the atmosphere or sea. The arrangements must in addition be such as to enable compliance with any requirements which may be agreed internationally as to the manner, rates and levels of such discharges. Facilities shall also be provided for the safe transfer of any stored wastes to the dockside. Monitoring devices shall be incorporated.

(20) An independent emergency source of electrical power, in addition to any required under rule (25), shall be provided, suitably located and capable of meeting the essential reactor and ship requirements other than for propulsion.

(21) The primary circuits and parts and assemblies which are essential for shutting down the reactor and absorbing decay heat shall be shock resistant to the satisfaction of the appropriate authorities.

(22) The design, construction and standdards of inspection and assembly of the reactor installation shall be to the approval and satisfaction of the appropriate authorities and shall take account of any limitations on periodic survey.

(23) The strength, stability, subdivision and structural fire protection of the ship shall be to the approval and satisfaction of the appropriate authorities, irrespective of whether the vessel is a passenger or cargo ship.

(24) Normally, the power supplied by the reactor to the main turbine or turbines shall be divided equally between at least two suitably separated systems. If it should be necessary to shut down any one system the reactor must be capable of continuing to operate safely on the remaining system or systems.

(25) Unless a ship has two or more reactors capable of independent operation, arrangements shall be provided whereby the ship can be propelled at a navigable speed for a period of not less than five days should nuclear power not be available.

(*Continued from page 169*)

containment structure by piping, electric wiring, etc.

It is evident therefore that attention should be directed towards reducing the containment pressure, since leakage can be taken to be roughly proportional to it. After an accident involving the invokement of the containment, the containment pressure will tend to:—

(i) Drop, due to heat transfer from the contained fluid to steelwork, etc.

(ii) Rise, due to the continued evolution of decay heat in the reactor core.

The drop in the pressure can in many cases be accelerated and increased by providing water sprays within the containment, arranged to come into operation automatically by a pressure signal. The quantity of water spray required is often found to be surprisingly small to achieve large pressure reductions, particularly if the reactor is of the water-cooled type. Despite the adoption of water sprays, however, the leak-tightness requirements are likely to cause many headaches.

If containment is invoked it is, of course, necessary to shut off all secondary circuit connections penetrating its walls. It is expected that heat generation in the reactor after the accident will be due only to decay heat, because either (a) it has been possible to shut down the reactor or (b) the reactor core has melted and thus the critical size has been lost. Naturally, endeavour in the design stages must be directed towards avoiding (b), which might lead to the deposition of a certain proportion of the fission products on the walls of the containment structure and thus result in a most serious radiological hazard. It will be noted that Recommendations Nos. 10 to 14 are designed to ensure that the reactor can always be shut down and its decay heat removed. Despite these Recommendations, No. 16 calls for shielding to give adequate short-term protection against radiations from fission products deposited within the containment, and is likely to require many tons of shielding around the containment structure in addition to local shielding in the control room and on the bridge.

Recommendation No. 10 calls for the safe removal of decay heat under all foreseeable operational and accident conditions at all angles of heel and list up to 70°. Compliance with this requirement involves the provision of a self-contained decay heat removal system, which must be independent of external power supplies.

The requirement to remove decay heat at an angle of list of 70° offers considerable scope for designers' ingenuity in providing a suitable, automatically operating, system powered either by natural circulation or possibly by steam generated by the decay heat.

Incidentally the sea, which is usually the most reliable of heat sinks, loses much of its attractiveness from this aspect when the ship is considered "in any attitude" (Recommendation No. 10). The accompanying illustration may look amusing but, if A is the cooling water inlet, the equipment served by it will run dry.

The limitations on the rate of change of reactor power referred to in Rec. No. 15 can arise from three causes:—

For power increase, from a limit on the allowable rate of control rod withdrawal, determined mainly from consideration of safety on start-up.

For power reduction, from the aspect of transient xenon poisoning, which may restrict the allowable rate to an unacceptably slow value if poisoning out of the reactor is to be avoided.

For any change, from a limit on the permissible rate of change of temperature of the stressed parts within the reactor primary circuit.

The dump steam system, which is usually put forward as a solution to these problems, can be based on the use of a special dump condenser, or alternatively can employ the main engine condenser as the heat sink. The choice will depend on the quality and maximum quantity of steam to be dumped. It is expected that, as reactor designs develop and experience becomes available with steaming of nuclear ships, the need for dumping steam will disappear.

The above discussion assumes that the reactor heat output will be arranged to generate steam, which will be used in steam turbine propulsion machinery. It follows that the main difference from a conventional steamship will be the omission of the main oil fired boilers with oil fuel and air systems, and their replacement by the reactor and associated heat exchangers. The nuclear part of the machinery installation will be arranged almost wholly within the containment structure. The remainder of the machinery will differ from its conventional counterpart in relatively minor, but nevertheless important, respects, including:—

(a) Provision of dump steam system, referred to above.

(b) Provision of means for auxiliary, non-nuclear, propulsion (Rec. No. 25).

(c) Provision of independent emergency source of electrical power and arrangements to ensure the maximum reliability of certain power supplies (Rec. No. 20).

(d) Provision of additional sea-water and fresh-water pumps and heat exchangers for reactor ancillary systems and for decay heat removal.

(e) Initial steam conditions at inlet to main turbines are likely to be considerably lower than in conventionally powered plants.

(f) Special attention may need to be paid to the quality and temperature control of the feed water.

(g) A control room for the centralized remote control of the reactor is generally considered to be essential. It is convenient to arrange also for control of the main propulsion machinery over the whole power range from this control room.

(h) Suitable arrangement of feed tanks, etc., can reduce the weight of reactor shielding required.

Not directly referred to in the above list, but of unquestioned importance, is the need to ensure that some fault in the conventional machinery, or its possible maloperation, will not threaten the safety and containment of the reactor. To confirm that all is in order, it is usual to examine the consequences of all conceivable failures of the conventional machinery systems, side by side with the examination of consequences of nuclear accidents and marine hazards.

It is expected that the results of these examinations would be included in the safety assessment, which would also include a proposed operation manual and would be submitted to the appropriate authorities in a manner generally similar to that adopted for land-based reactors.

It is hoped that this very brief review of a few aspects of the committee's recommendations will serve as an introduction to them and will engender further comment. The overall effect of the recommendations can best be gauged in a complete study encompassing the whole machinery installation, such as was carried out by Y-A.R.D. in connection with the proposals submitted to the Galbraith Committee.

HTGR

General Atomic's Advanced Design

AN attempt to combine the high power density of the liquid cooled reactor with the high temperatures of the gas cooled reactor, recently described* in the U.S., is scheduled for completion in 1963. Under contract with the AEC, General Atomic (division of the General Dynamics Corporation) is carrying out the nuclear design of a 40 MW prototype plant, which will be owned and operated by the Philadelphia Electric Company, one of a group of 53 utility companies forming a non-profit corporation, High Temperature Reactor Development Associates, Inc., who are sponsoring the project.

Some idea of the advanced nature of the design is given by the core rating. This, at 8 kW/litre, is nearly one-third of that of the BWR, is four times that of the EGCR and 20 times that of Calder Hall. The homogeneous design of the core, the use of fissile-fertile fuel, the high gas temperatures, and the long burn-up expected, are other characteristics.

The main parameters of the HTGR are given in Table 1, and the general arrangement of the reactor is shown in Fig. 1.

TABLE 1
Main Parameters of HTGR

Thermal output	115 MW
Electrical output	40 MW
Thermal efficiency	34.8%
Core	
Diameter active	9 ft
Diameter over reflector	13 ft
Length active	7 ft 6 in.
Length overall	11 ft 6 in.
Weight of graphite, including reflector	67.2 tonnes
Coolant voidage in core	12.8%
No. of fuel elements	810
Dia of fuel elements	3.5 in.
Burn-up ($U^{235}+Th^{232}$)	75,000 MWd/te
Investment (U^{235})	190 kg
Investment (Th)	1,190 kg
Fissions/original fissile atoms	0.63
Graphite/uranium ratio	1,900
Max. fuel surface temp.	2300°F (1260°C)
Coolant etc.	
Inlet temp.	660°F (349°C)
Outlet temp.	1380°F (749°C)
Pressure	20 atm
Flow rate	80,000 cu ft/min (480,000 lb/h)
Steam flow	367,000 lb/h
Steam	1000°F (538°C)
Steam pressure	1450 p.s.i.a. (102 kg/cm²)
Reactor pressure vessel dia	14 ft
Reactor pressure vessel height	34 ft

Core

The core, which is homogeneous in that it contains only fuel elements and coolant space, has over 800 fuel elements 3½ in. dia made up into an approximate cylinder 9 ft. dia, surrounded by a graphite reflector. The fuel elements consist of fuel and graphite compacts (either cylindrical or annular with graphite plugs) and end reflector plugs, all contained within a graphite sleeve. Since the fuel compacts are expected to run at 2,000-3,000°F, much of the heat transfer to the sleeve will be by radiation, eliminating the interface temperature drop. (The small space between the compacts and the sleeve also assists with fission product purging, dealt with below.)

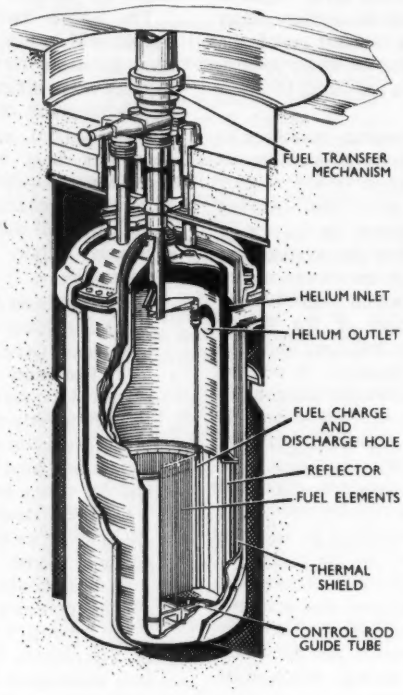


Fig. 1.—General arrangement of the HTGR.

The fuel itself is a mixture of highly enriched uranium and thorium, optimization studies having shown economic advantages over slightly enriched uranium —in fact, in large size reactors it is expected that the major portion of the energy in a single core loading will come from the bred U^{233}. The fuels are present in the form of carbides dispersed in a graphite matrix, the proportions of U, Th, and graphite being about 1, 10, and 700 (ats.).

The fuel elements require extensive development, and there is a distinct possibility that the plant may commence operation with metalclad fuel elements, with a gradual change-over to the graphite cladding. Initial steam temperatures will not, therefore, be as high as the final design figures, although it is expected that steam temperatures of 850°F (454°C) will still be obtainable, with a reduced power output of 25-30 MW.

Control

The control rods consist of boron carbide dispersed in a graphite matrix, and are operated from below the reactor. Three sources of power are provided—pneumatic, hydraulic, and mechanical—and, in normal operation, hydraulic power with a differential piston provides a net downward force to hold the rod against a "position" stop, mechanically adjusted by a motor-driven ball-screw actuator. For scramming purposes, hydraulic pressure is removed from the top of the differential piston; an orifice in the discharge line limits the rod velocity. To ensure "fail safe" operation, the mechanism is designed so that either pneumatic or hydraulic power, acting alone, will scram the reactor.

Coolant and Purging

The main coolant is helium, at a pressure of around 300 p.s.i., which enters the reactor at 660°F and leaves at 1,380°F. By the use of concentric flow throughout, including the gas ducts, all pressure parts, including the reactor vessel, are only exposed to the lower temperature, so that carbon steel may be used for most of the structural parts. It is interesting to note, by the way, that the high operating temperatures permit of a steam generator having about 1/20th of the volume of the Calder steam generators for approximately the same power output.

Circulation of 80,000 cu ft/min of helium is by two blowers in series, the pressure rise is some 5 p.s.i. across each blower. The driving motors are 2,500 h.p., with speed control by variable frequency. To prevent helium leakage, each blower and motor unit is completely canned: there is, however, a labyrinth shaft seal between the two, fed with clean helium, to prevent possible contamination of the motor.

Recognizing that no cladding material is completely impervious to fission products at these temperatures, the approach adopted is to contain as much as possible by relatively impervious graphite, and to remove the remainder by a helium purge between the compacts and the graphite. This purge stream flows from the bottom of the element to a trapping system, possibly of activated charcoal, the system being refrigerated towards the final stages. This is being adopted in preference to the more conventional purification by-pass loop on the primary circuit; condensable

*Abstract of paper "The HTGR, an advanced high-temperature gas cooled graphite moderated reactor," by Corwin L. Rickard (General Atomic Division of General Dynamics Corporation) at the Gas Cooled Reactor Symposium sponsored by the Franklin Institute and the American Nuclear Society, Philadelphia, Feb. 10-11, 1960.

fission products are prevented from "plating out" in the primary circuit, and the trapping problem is simplified in that the fission products reach the trapping system relatively undiluted.

Apart from fission products, however, there is a by-pass purification system for the helium, to remove oxygen, nitrogen, water vapour, and entrained solids.

Preliminary design and development of the HTGR was initiated early in 1957, and an extensive programme is proceeding at present on control rod drives, fuel elements, charge mechanisms, steam generators, blowers, and valves.

The Bechtel Corporation is the prime contractor to Philadelphia Electric for the prototype plant construction.

MGCR

Marine Gas Turbine Reactor Study

BERYLLIUM oxide as a moderator is the feature of outstanding interest in a marine reactor study* being carried out by General Dynamics Corporation, jointly sponsored by the U.S. AEC and the U.S. Maritime Administration. The project comprises two advanced systems, a high temperature gas cooled reactor, and a helium-powered closed-cycle gas turbine equipment.

Reactor Design

Very few details are available of the reactor system but it would appear that extremely high temperatures are contemplated. Unlike the HTGR previously described, present proposals favour a heterogeneous design with metallic fuel canning and this, combined with the information that the outlet temperature is in the range of 1,350-1,500°F (735-815°C) appears to be on the high side for metal canning. [*A separate paper was devoted to the question of materials and fuel elements at the symposium but this is not available.*—Ed.] There are, however, hints that niobium or molybdenum may be considered as possible alternatives to stainless steel.

The only other information available regarding the fuel elements is that they are arranged as 19-rod bundles with approximately ¼-in. diameter rods. There is also a suggestion that instead of using uranium dioxide the fuel might be diluted with material such as beryllium or aluminium oxides. This would give greater safety because of increased thermal capacity and possible improvement in fission product retention.

The loading of U^{235} is specified as 208 kg and it is estimated that the core lifetime, assuming a uniform burn-up, will be more than 4 years of full power. The size of the proposed core is 6.4 ft in both dimensions (without reflector).

Gas Turbine

The gas turbine is to operate on a fairly conventional closed circuit and is rated at 22,000 s.h.p.

The development programme for the propulsion plant itself will be extensive, one of the major problems being the heat exchanger design. Another problem, unrelated to reactor design but which will have to be solved, is the development of a low-cost efficient reversing mechanism.

The present development schedule envisages—even at the lower reactor temperature of 1,350°F (735°C)—a basic cycle efficiency of upwards of 32%.

An alternative steam cycle has been studied operating at 850 psi, 900°F (482°C) with gas temperature of 1,300°F (704°C).

The present schedule assumes that approval and construction of the MGCR prototype will permit test operation by early 1964.

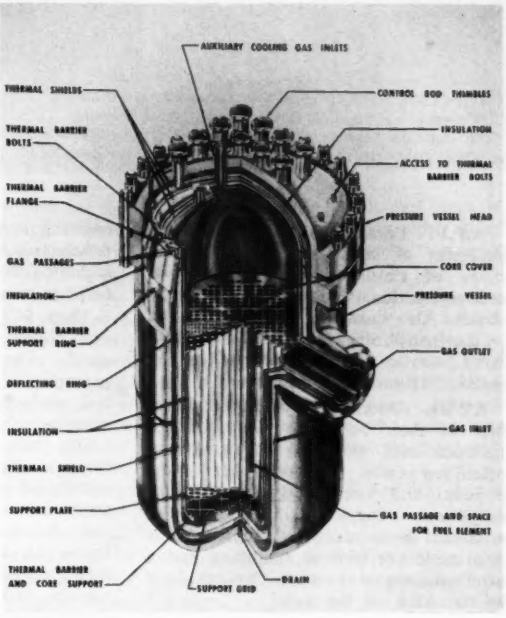
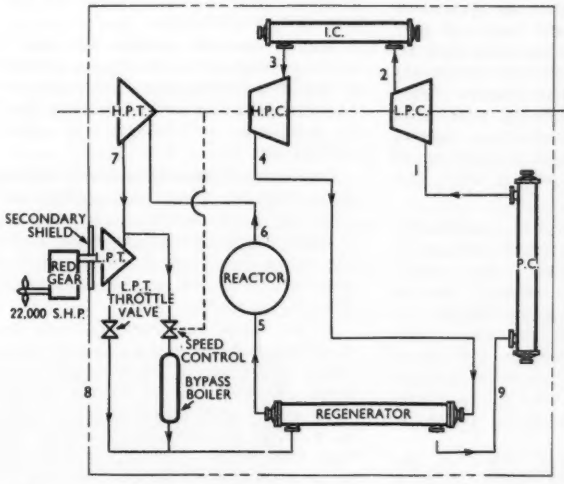


Fig. 2.—Cutaway drawing of the MGCR.



Cycle Temperatures in °F.

(Italic figures are approximate equivalents in °C.)

1	85	*(29.4)*
2	236	*(113)*
3	85	*(29.4)*
4	207	*(97)*
5	753	*(400)*
6	1,300-1,500	*(704-815)*
7	1,005	*(541)*
8	835	*(446)*
9	294	*(146)*

Absolute Pressures in p.s.i.

(Italic figures are approximate equivalents in kg/cm².)

1	308	*(21.5)*
2	520	*(36.6)*
3	518	*(36.5)*
4	800	*(56.2)*
5	778	*(54.5)*
6	739	*(52)*
7	446	*(31)*
8	311	*(21.8)*
9	310	*(21.7)*

Fig. 3.—Simplified schematic diagram of gas turbine circuit, showing temperatures and pressures at various points.

Helium Flow 75 lb./sec.	Basic Cycle Efficiency	Overall Efficiency
Pressure Ratio 2.6%	32.9%	30.8%

*Abstract of paper "Maritime Gas Cooled Reactors" by Harry L. Browne (General Atomic Division of General Dynamics Corporation) at the Gas Cooled Reactor Symposium sponsored by the Franklin Institute and the American Nuclear Society, Philadelphia, Feb. 10-11, 1960.

ENGINEERING MATERIALS AND DESIGN EXHIBITION

A general view of the AWRE stand displaying the work this establishment has done on beryllium.

The first Engineering Materials and Design Exhibition and Conference was held at Earls Court from February 22-26. More than 20 papers were read and exhibitors expressed satisfaction at the amount of interest shown in their stands.

A.P.V. Paramount had on show examples of castings in the Paralloy range of stainless, special alloy and carbon steels, including fuel element stands. Also shown by them, but located on the British Steel Founders Association stand, was a reactor guide pan casting in BS 592B steel for Hunterston.

AWRE, Aldermaston displayed examples of their beryllium work. These included cast, sintered, fabricated and machined pieces. A brief review of the physical and mechanical properties of beryllium, including the physics approach to the ductility problems, was also made available at the stand and a brief synopsis of the research work done by the AEA on the metal.

Dewrance included demonstrations of their hardfacing process as applied to flat deposits, shafts, rod and high temperature brazing. They also had on display their Endewrance hardfacing materials in rod and powder form, examples of depositioning with their alloys and high temperature brazing alloys. Exhibits of brazed assemblies and castings in various metals were also shown.

The **Ferranti** stand had examples of castings in S.G. Iron and Nodumag, an austenitic non-magnetic type metal which incorporates several unusual physical qualities. It is an alloyed ductile non-magnetic cast iron with a yield point of 18-22 tons/sq. in. and has a high impact resistance. A recent development of its use has been in the manufacture of stator pressure plates in turbo-alternators.

Examples illustrating some of the essential points in the design of stainless steel products and methods of fabrication showed the interest **Firth-Vickers Stainless Steels** have displayed in the production of stainless, heat and creep-resisting steels over the past 40 years. A selection of this company's products, including bars, sheet strip, plate and forgings was also displayed.

Three **ICI** divisions, Metals, Dyestuffs and Nobel, exhibited together on one stand. The Metals section included examples of nuclear fuel element cans and products in zirconium, titanium and other new metals. This division's exhibition was held in conjunction with Imperial Aluminium and also included aluminium and copper products. Synthetic resins comprised the Dyestuffs show and the application of polyurethane foams by spray was illustrated. The Nobel division concentrated on silicone rubbers and resins for mechanical and electrical work, including heat resistant paints in silicone and lubricants for high and low temperatures.

Special stainless needles for use in nuclear energy were among the exhibits of **Ina Needle Bearings.** Other exhibits included precision needle rollers supplied to tolerance on diameter of about 0.00004 in.

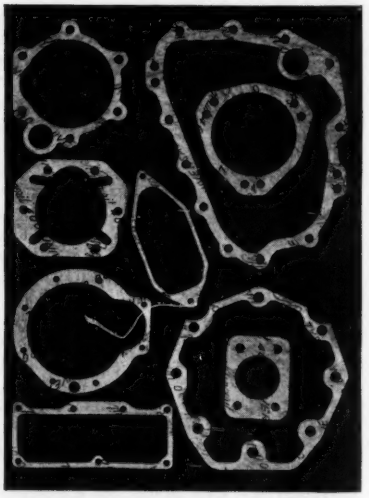
International Meehanite Metal showed their Meehanite metal, a high-duty cast iron which is manufactured by 200 licensed foundries throughout the world. Literature illustrating the wide range of uses for Meehanite castings was available on the stand.

E. G. Irwin and Partners, who are designing and building a hot cave laboratory at Windscale, showed their wide range of services which include design, development and consulting engineering in a series of photographs. Views of their own offices, workshops and laboratories were also displayed.

A demonstration of low temperature silver brazing alloys and fluxes was carried out throughout the show on the **Johnson, Matthey** stand. This firm also showed precision drawn seamless tubes in non-ferrous metals and alloys, electrical contact and contact materials and materials and components for electronic and instrument engineering.

Lake and Elliot had on display black and machined castings in carbon and alloy steels and in grey iron and S.G. iron, including precision castings.

The Langalloy range of corrosion and heat resisting stainless steels and nickel was exhibited by **Langley Alloys** as well as their Hidurax aluminium bronzes and Hidurel high strength high conductivity alloys. Examples of stampings and castings, sand and shell moulded, as well as forged and rolled products were on view.



Examples of gaskets for extremely high temperatures and pressures made from the Klingerit 400 Universal compressed asbestos jointing material by Richard Klinger.

Among the Sintox precision engineering ceramics on the **Lodge Plugs** stand was the special grade which has been produced for the nuclear industry. It has a low neutron capture cross-section and good compatibility with other materials used in reactor design.

Low Moor Alloy Steelworks concentrated on stainless, heat resisting and corrosion steels of various types and showed examples of high speed steels, hot die steels and tool steels. On the same stand, **Low Moor Fine Steels** displayed extruded steel sections in solid and hollow shapes of mild, carbon, alloy, stainless and heat resisting steels.

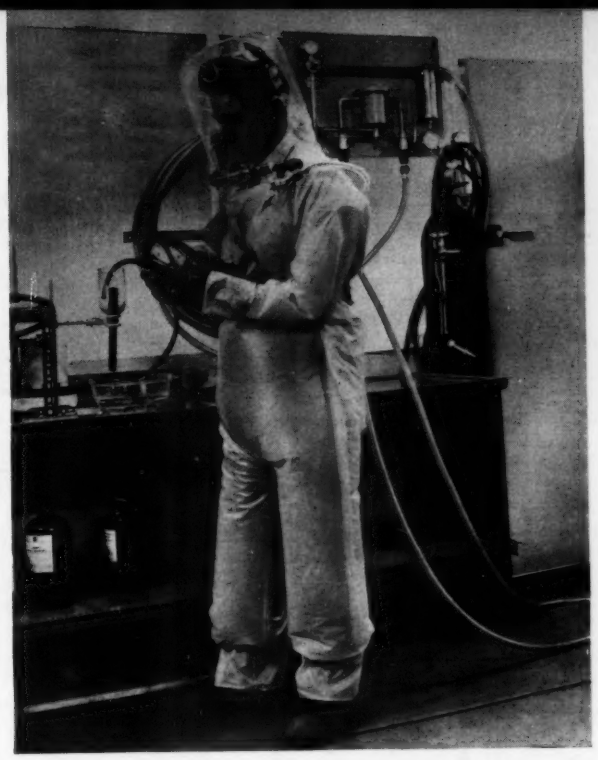
An interesting exhibit was that of the **Magnesium Council** who showed the versatility of magnesium in its current applications. This included magnesium anodes for cathodic protection.

A comprehensive exhibition of the wide range of silicones now available for designers was shown by **Midland Silicones.**

A working model of a furnace incorporating the Morgan crusilite carbide electric furnace heating element, was exhibited by **Morgan Crucible.** The elements are made in the form of a tube of uniform diameter with a helical slot machined in the centre portion of the tube permitting the current to flow in a spiral path. The resistance per unit length of element is therefore considerably higher in the centre than in the unmachined ends. This allows the heat dissipation to be localized in the central portion, leaving the ends which pass through the furnace wall to electrical connections cool, eliminating a potential source of failure between the hot zone and cool ends.

Samuel Osborn included examples of titanium and special corrosion and heat resisting alloy products on their stand. Their application was well illustrated by a model of a heat exchanger and pump for handling corrosive liquids. In addition they showed their Socast steel castings which are produced by the Osborn Shaw and Osborn shell mould CO_2 process. A selection of extruded steel sections was also shown.

Exhibits of plastics engineering materials were displayed by **Polypenco.** These included a molybdenum disulphide filled nylon 66 product, Nylatron GS, available as an injection moulding powder and in extruded shapes. Corvel coated parts and coating powders for use in the fluidized bed process were shown and a new low moisture absorption, high impact resistant thermoplastic in extruded rod form was shown for the first time. The Nylaflow flexible pressure hose and tubing that has a burst pressure rating of up to 8,000 p.s.i. was included in the exhibition.



The Spembly protective suit made from Geon PVC for use against radioactive dust, gases and toxic fumes. The suit has been introduced by Spembly and Chatham and Plysu Products.

Royal Worcester Industrial Ceramics were another exhibitor in the ceramic field. They showed selections of their non-felspathic porcelain for carbon and wire-wound resistor manufacture, and a high alumina ceramic, Regalox, which has high resistance to wear, is not affected by high working temperatures and in addition possesses excellent high density and physical properties. The extreme hardness of this material is an additional attraction in nuclear engineering.

The Ruston and Hornsby Ruston-Grayloc high pressure high temperature, all metal connections were also on show. These connections are made to match standard pipe sizes from one to thirty inches, for butt, socket weld or threaded connections. They consist of a seal member with lips, hubs on which the lips bear to form the seal with a two or three bolt clamp. The connections may be repeatedly broken and re-made using the same seal member.

Another firm showing shell moulded, machine and hand moulded castings was **Sheepbridge Alloy Castings.** Their products were stainless, heat resisting steels and complex nickel base alloys such as Hasteloy, Illium and Nimocast. This firm also do centrifugally cast rings, pots and tubes in iron, carbon steel, aluminium and manganese bronze, cupro-metal and bi-metals.

Examples of **Vickers - Armstrongs (Engineers)** wide range of extruded, rolled and cast copper alloys were displayed and details of a range of special alloy iron and steel castings were shown with illustrations of their applications. **Ioco,** who were on the same stand, showed mechanical and electrical engineering plastics and rubbers including Linapex, Linapol and Terapex electrical insulations.

Charles Weston exhibited their range of seals which include synthetic rubber mouldings made to customers' own designs.

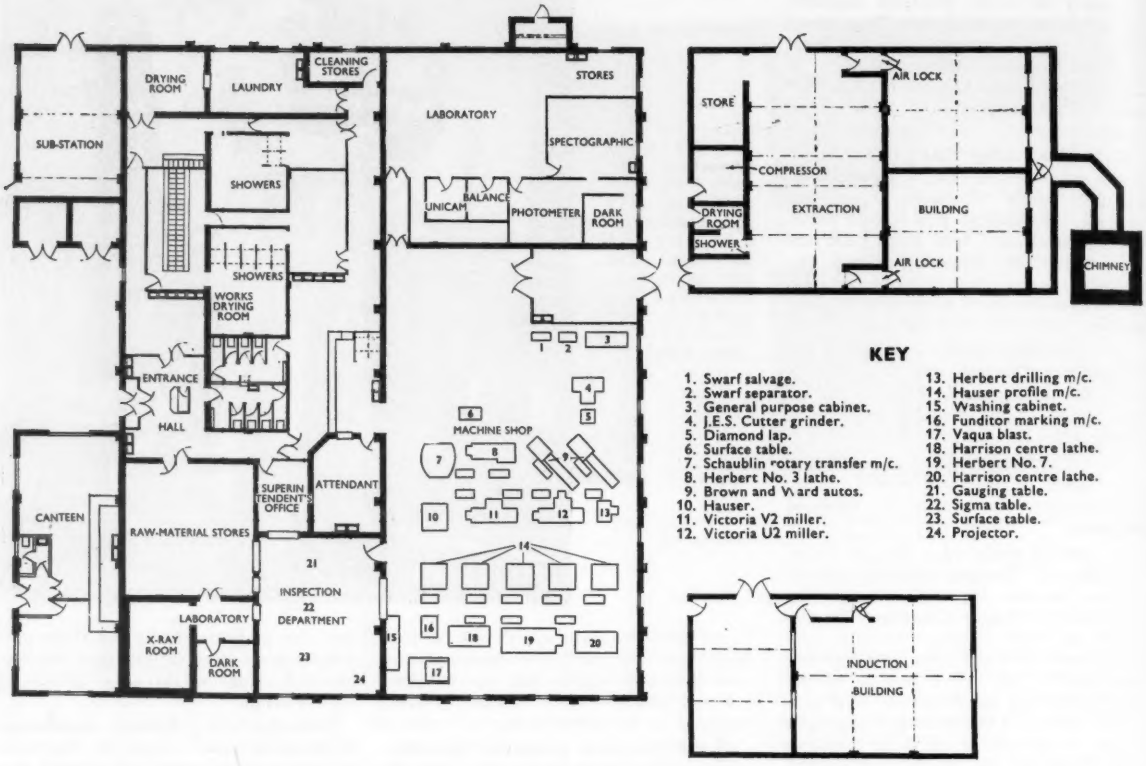
Henry Wiggin, makers of wrought nickel in all commercial forms were also at the show. This firm make Corronel corrosion-resisting alloy and Ni-o-mel nickel, iron, chromium alloy for corrosion resistance, electrical resistance materials and thermometal for bi-metallic temperature control.

Ni-resist castings and non-magnetic castings which have an application for nuclear engineering were shown by **John Williams** of Cardiff. This firm also exhibited castings showing the wide applications available for spheroidal graphite and alloy iron.

Wilmot Breeden's range of Truflo butt weld pipe fittings in stainless steel and high duty alloys was displayed. Heat exchanger matrices, hollow blades for gas turbines and pipe couplings were all on their stand as well.

A fine display was the **Zinc Alloy Die Casters Association's** which included a large variety of functional and decorative pressure die castings in zinc alloy and light alloys.

The Morgan Crucible crusilite carbide electric furnace heating element supplied with resistance values measured at 800°C.



KEY

1. Swarf salvage.
2. Swarf separator.
3. General purpose cabinet.
4. J.E.S. Cutter grinder.
5. Diamond lap.
6. Surface table.
7. Schaublin rotary transfer m/c.
8. Herbert No. 3 lathe.
9. Brown and Ward autos.
10. Hauser.
11. Victoria V2 miller.
12. Victoria U2 miller.
13. Herbert drilling m/c.
14. Hauser profile m/c.
15. Washing cabinet.
16. Funditor marking m/c.
17. Vaqua blast.
18. Harrison centre lathe.
19. Herbert No. 7.
20. Harrison centre lathe.
21. Gauging table.
22. Sigma table.
23. Surface table.
24. Projector.

Machining Beryllium

New Armstrong Whitworth Facility at Whitley

THE commissioning of a completely new facility for machining beryllium within a year of being asked to tender is a remarkable achievement. Armstrong Whitworth Aircraft—who have done just this at their Whitley establishment—have, at the same time, demonstrated their awareness of the need for rapid inauguration of specialist machining techniques in nuclear engineering.

Although primarily an aircraft manufacturing company, A.W.A. are by no means newcomers to nuclear work. At their Baginton factory, for example, the company has already been responsible for machining Magnox fuel cans under an AEA contract. This work was done at low cost by adapting existing machine tools rather than installing purpose made tools.

Possibly the invitation to tender for machining beryllium came as a direct result of the ingenuity shown in the production of Magnox fuel elements. Although at that time (February, 1959) beryllium was new to A.W.A., the metal was considered to have interesting possibilities and a tender was prepared. This was accepted by the AEA some weeks later, and almost immediately a project committee was formed to speed the establishment of the new facility. Remarkable progress was made in spite of the lack of any experience of machining the metal in quantity. Plans were completed in June last year and the whole factory (nearly 20,000 sq. ft.) was complete and ready for commissioning on February 17 this year.

Beryllium does not present any particular machining problem except for the removal of the dust which is highly toxic. Beryllium is a light, soft metal and as such its machining characteristics are somewhat similar to those of aluminium.

Initially the factory will be producing AGR components, the output being 200 fuel element end caps per hour, 20 thermocouple elements per week and 200 element support plates per week.

A high standard of accuracy is called for and tolerances are of the order of $\pm$ 0.001-in. on dimensions and $\pm$ 0.002-in. so far as the position of holes or other features are concerned.

After machining there is a 100% check on all AGR components—a Sigma comparator gauging system has been installed for this purpose. In addition the inspecting staff can also check the profile of a component on a Hilger projector whilst a 100 kV Macrotank B fine focus unit caters for any radiographic requirement.

Quite apart from the inspection room there is a separate well-equipped laboratory containing weighing devices, vacuum furnaces, and equipment for spectrographic analysis. All swarf arising from machining operations is collected in two-stage dust collection units developed by Mancuna Engineering and is then carefully examined for any contamination that might occur during machining.

As can be seen from the accompanying illustration, the

space devoted to the actual machining is small in comparison to the size of the factory. Because of the health hazard associated with the dust the building is divided internally into contact areas, in which the metal is being handled in such a way as to merit full protection techniques or non-contact areas where no precautions are necessary, either because the beryllium is always contained in transit boxes or is never present.

The contact area is contained in a pressure shell supplied with filtered and heated air which is changed every three minutes. This air is drawn in through the end wall of the induction building, heated, filtered, passed to the main building and subsequently exhausted. Before it leaves the building it is passed through an elaborate system of absolute filters and is then returned to atmosphere via a 120-ft chimney.

A secondary extraction system working at very high air velocities (50,000 c.f.m.) removes all swarf produced during the machining operations. For this purpose each machine tool is encased in a glove box into which beryllium components are placed and removed through a water trap which effectively limits the possibility of swarf being carried out with the components.

The whole building has been designed to prevent any fire hazards upsetting the elaborate health protection precautions. All furniture, partitions and equipment are made of steel and the building fabric is of fire-resistant materials.

Monitoring for air contamination is carried out and the permissible limit is 2 microgrammes per cu. metre. To avoid risk of interference with monitor sample analysis the company has built a self-contained health monitoring laboratory 2½ miles away at Baginton. As an additional safety precaution in starting up the facility all operators were required to wear pressure suits. Subsequently, when sufficient checks have been made, face masks will be worn. Later still, providing results are acceptable, operators will wear protective overalls.

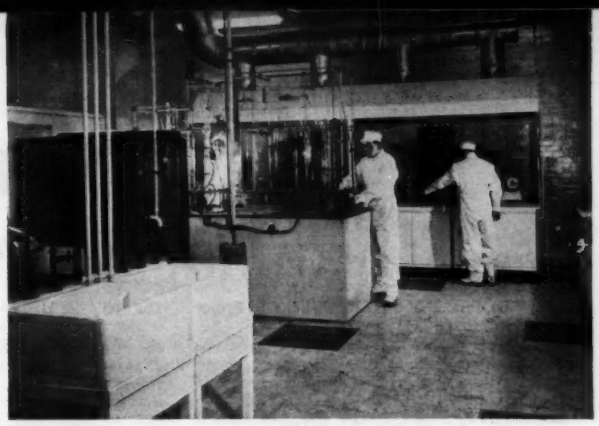
LIST OF MANUFACTURERS

MAIN BUILDING CONTRACTORS AND SUPPLIERS

A.E.I. Lamp and Lighting Co., Ltd., Melton Road, Leicester.
Fluorescent lighting.
Braithwaite and Co. (Structural), Ltd., Neptune Works, Newport, Mon.
Brush Electrical Co., Ltd., Loughborough.
Electric motors for blowers.
Carrier Ross Eng. Co., Ltd., 22A Cavendish Square, London, W.1.
Air conditioning installation.
Chimneys, Ltd., 351 Lower Addiscombe Road, Croydon, Surrey.
Ventilation shaft.
Docker Bros., Rotton Park Street, Birmingham, 16.
Epifin 457 enamel paint for walls; Syntholux machine tool finish.
W. H. Heywood and Co., Ltd., Bayhall Works, Huddersfield.
Insulations and Partitions, Ltd., 40B Humber Avenue, Coventry.
Kelvin Construction Co., Long Drive, Greenford, Middlesex.
Limmer and Trinidad Lake Asphalt Co., Ltd., Trinidad House, Coventry Street, Birmingham, 5.
Mancuna Eng., Ltd., Denton, Manchester.
Fifteen two-stage dust extraction units.
Midland Heating and Ventilation, Ltd., Bedford Road, Birmingham, 11.
Minerva Detector Co., Ltd., Richmond, Surrey.
Minerva fire detection system comprising 42 detectors connected in five groups to a main control unit.
National Brick Co., Ltd., Heather, Leicester.
Norwood Steel Co., Ltd., Howard Way, Harlow, Essex.
Parker, Winder and Achurch, Ltd., Broad Street, Birmingham.
Pyrene Co., Ltd., Great West Road, Brentford, Middlesex.
Vokes, Ltd., Henley Park, Guildford, Surrey.
Air filters.
T. Wilson and Son, Ltd., 65-67 Sheep Street, Northampton.

MAIN PLANT AND EQUIPMENT SUPPLIERS

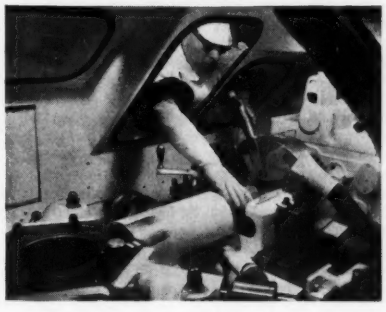
Abrasive Developments Ltd., High Street, Henley-in-Arden, Solihull.
Vaqua Blast cleaning unit.
Baird and Tatlock Ltd., Walthamstow, London, E.17.
Micro vacuum fusion apparatus for the determination of oxygen in beryllium.
British Laundry Machinery Co., Ltd., Alperton, Wembley.
Broom and Wade Ltd., High Wycombe.
British Vacuum Cleaner Co. Ltd., Sherlock Street, Birmingham 5.
Vacuum cleaners.
Crompton-Parkinson Ltd., Seven Street, Birmingham.
Coventry Electrical Appliances Ltd., Wheatley Street, Coventry.
Edwards High Vacuum Ltd., Manor Royal, Crawley, Sussex.
RB4 vacuum pumps for air monitoring equipment.
Griffin & George (Laboratory Construction) Ltd., Morden Road, Mitcham, Surrey, in association with **Grundy Equipment, Ltd.**, Cowley, Middx.
Metal laboratory furniture, fume cupboards and hoods.
T. S. Harrison and Sons Ltd., Heckmondwike, Yorkshire.
Lathes.
Hilger and Watts Ltd., 98 St. Pancras Way, London, N.W.1.
Medium quartz spectrograph and Polyprint 12, a direct reading model.
Alfred Herbert Ltd., Coventry.
Turret lathe.
W. E. Jones (Tools) Ltd., East Street, Coventry.
Milling machines.
Jones and Shipman Ltd., Leicester.
Loughborough Glass Co. Ltd., Leicester.
Radyne Radio Heaters Ltd., Eastheath Avenue, Wokingham, Berks.
H.F. heating equipment.
Research and Control Instruments Ltd., 207 King's Cross Road, London, E.C.1.
Radiographic examination equipment.
Unicam Instruments Ltd., Arbury Works, Cambridge.
A.C. Wickman Co. Ltd., Coventry.
Windley Bros., Chelmsford, Essex.
Surfacing table.



Swarf analysis laboratory showing vacuum fusion unit.

(Right) A general view of the machine shop, the surfacing table being in the foreground.

(Below) All machine tools are totally enclosed: this photograph shows the normal operation of a lathe.



TRANSLATIONS

Résumés of Principal Articles

Le Role Joué Par " HERO " dans le Projet " AGR " (page 149)

L'article passe en revue le programme du réacteur gaz-graphite de type avancé, connu sous le symbole d'AGR. Le rôle qui sera joué par le réacteur d'énergie nulle " HERO " est analysé. Les deux réacteurs seront critiques à peu près au même moment. La construction dans son ensemble et les possibilités spéciales des installations sont décrites. Il sera possible en particulier, de faire fonctionner le réacteur, les 19 canaux centraux étant ou beaucoup plus chauds ou beaucoup plus froids que les canaux périphériques; ceci permettra de mesurer avec précision les coefficients de température.

Les Réacteurs de Recherche (page 154)

Durant les deux dernières années un nombre considérable de réacteurs de recherche ont été lancés sur le marché mondial. Les modèles disponibles vont du petit réacteur d'un milliwat destiné à l'entrainement de personnel jusqu'au réacteur de recherche de puissance élevée ou destiné à l'essai des matériaux.

Effets de l'Irradiation sur les Eléments de Combustible de Calder Hall (page 160)

Plus de 1000 éléments de combustible ont été choisis après irradiation dans les réacteurs de puissance de Calder Hall et ont été soumis à des examens serrés. 25 éléments défectueux ont été détectés en deux ans et demi. L'article est consacré à une analyse des défauts constatés, et suggére que les défaillances dues à l'irradiation sont plus probables à basse température. Alors la ductilité de la gaine est moindre et le combustible est plus enclin au gonflement dû à l'irradiation.

La Manipulation du Combustible a la Centrale de Berkeley (page 164)

La centrale nucléaire de Berkeley est construite par A.E.I.-John Thompson pour le compte du Central Electricity Generating Board (l'E.D.F. anglais). Berkeley sera l'une des premières centrales où les éléments de combustible pouvront être changés durant la marche du réacteur. Plusieurs machines spéciales ont été conçues à cet effet par l'entreprise John Thompson: machines de chargement, de déchargement du réacteur, glissière, équipement, d'observation visuelle, outillage pour l'entretien et la réparation des barres de contrôle, etc. L'article décrit l'utilisation de cet équipement. En autre il résume rapidement quelques-uns des principes régissant le changement d'éléments de combustible durant la marche du réacteur.

La Securité des Navires Marchands a Propulsion Atomique (page 169)

Le Ministère des Transports vient de promulger des directives pour l'étude et la construction des navires à propulsion atomique. Un panorama des directives est présenté en même temps qu'un mode d'emploi devant permettre leur correcte interprétation.

Le Façonnage du Béryllium (page 176)

La décision d'utiliser le béryllium pour les gaines des eléments de combustible du réacteur AGR a obligé à concevoir des machines-outils adaptées au façonnage de ce nouveau matériau. La poussière produite lors de cette opération doit être évacuée. Il s'agit là du problème principal posé par l'utilisation du béryllium. Les usines de Sir W. G. Armstrong Whitworth Aircraft Ltd. situées à Whitley ont été pourvues d'installations spéciales réservées exclusivement au façonnage du béryllium. Ces nouvelles installations couvrent une superficie de près de 2100 m^2.

Die Stelle des HERO im AGR-Plan (Seite 149)

Der Arktikel gibt einen Ueberblick über das weitere Programm für den gas-gekühlten Reaktor und erörtert die Rolle, die dabei der Nullenergie-Reaktor HERO spielen soll, der das kritische Stadium ungefähr um dieselbe Zeit erreichen wird wie sein krafterzeugendes Gegenstück. Er beschreibt die Konstruktion im allgemeinen und die besonderen Möglichkeiten, die durch ihn geboten werden—insbesondere die Fähigkeit, ihn zu betreiben mit den 19 zentralen Kanälen sowohl beträchtlich kälter als auch beträchtlich heisser als die äusseren Kanäle, sodass genaue Messungen der Temperatur-Koeffizienten gemacht werden können.

Forschungs-Reaktoren (Seite 154)

Eine beträchtliche Zahl von Forschungs-Reaktoren ist während der letzten beiden Jahren auf dem Weltmarkt erschienen. Ihre Grössen gehen vom kleinen Milliwatt Reaktor für Uebungszwecke bis zum Hochleistungs-Forschungs- und Untersuchungs-Reaktor.

Veränderung von Brennstoffelementen in Calder Hall unter Bestrahlung (Seite 160)

Ueber 1000 ausgewählte Elemente, die aus dem Leistungs-Reaktor in Calder Hall entfernt wurden, wurden einer kritischen Prüfung unterzogen. In 2½ Jahren wurden 25 Fehler in Brennstoffmänteln entdeckt. Der Aufsatz analysiert die Fehler und gibt der Vermutung Ausdruck, dass Fehler, die auf die Bestrahlung zurückzuführen sind, wahrscheinlich bei niedriger Temperatur entstehen, wenn die Nachgiebigkeit des Mantels besonders gering ist, und der Brennstoff besonders geneigt ist, unter Bestrahlung sich zu dehnen.

Die Behandlung des Brennstoffs in Berkeley (Seite 164)

Das Atomkraftwerk Berkeley, das z.Zt. von A.E.I.—John Thompson für die CEGB gebaut wird, wird eines der ersten kommerziellen Werke sein, die mit Einrichtungen arbeiten, um Brennstoff " unter Last " auszuwechseln. John Thompson Ordnance haben dafür eine Serie von Spezialmaschinen entwickelt und zwar sind dies Vorrichtungen, um den Brennstoff einzuführen und zu entfernen, Gleitbahnen, Möglichkeiten zur direkten Beobachtung und zur Rückgewinnung, zum Unterhalt von Kontrollstäben und Betätigungseinrichtungen. Der Aufsatz beschreibt die Handhabung dieser Vorrichtungen und erwähnt kurz einige der speziellen Erfordernisse für das Auswechseln von Brennstoff " unter Last."

Die Sicherheit der mit Atomkraft getriebenen Handelsschiffe (Seite 169)

Das Verkehrsministerium hat kürzlich eine Liste zu empfehlen der Massregeln für die Konstruktion und den Bau von mit Atomkraft getriebenen Schiffen herausgegeben. Es wird eine Zusammenfassung der Regeln gebracht und eine Anleitung zu ihrer korrekten Auslegung.

Die Bearbeitung von Beryllium (Seite 176)

Der Beschluss Beryllium als Mantelmaterial fuer AGR Brennstoff-elemente zu verwenden, hat den Bedarf fuer Bearbeitungs-Möglichkeiten geweckt. Das Hauptproblem, das bei der Bearbeitung von Beryllium gelöst werden muss, ist sicher zu gehen, dass aller Staub, der während der maschinellen Bearbeitung entsteht, aufgefangen und abgeführt wird. In den Fabriken in Whitley der Sir W. G. Armstrong Whitworth Aircraft, Ltd. sind Werkstätten, die eine Fläche von 20.000 Quadrat-Fuss (rd. 1850 m^2) bedecken, speziell für die Bearbeitung von Beryllium gebaut worden.

El Lugar Ocupado por HERO en el Proyecto AGR (pág. 149)

Pasando en revista el programa de reactor enfriado por gas avanzado, este artículo explica el papel que será jugado por el reactor HERO de energía cero, que llegará a la criticalidad aproximadamente al mismo tiempo que su contraparte productor de energía. Describe la construcción general y las facilidades especiales que dicho reactor hará que sean disponibles—particularmente la habilidad de funcionar con los 19 conductos centrales ya sea considerablemente más frios o más calientes que los conductos exteriores, así permitiendo que se tomen medidas exactas de los coeficientes de temperatura.

Reactores de Investigación (pág. 154)

En los dos últimos años se han puesto a la venta en el mercado mundial un número considerable de reactores para la investigación. Comprenden desde los reactores más pequeños en MW para fines de entrenamiento hasta los reactores de pruebas y altas potencias.

Cambios en los elementos de combustible de Calder bajo irradiación (pág. 160)

Más de 1.000 elementos seleccionados descargados de los reactores de Calder Hall han sido sometidos a un examen crítico. En 2½ años unas 25 fallas de recipientes de combustible fueron detectados. Este artículo presenta un análisis de estas fallas y sugiere que la falla debida a irradiación es probable que ocurra a las temperaturas más bajas donde la ductilidad del recipiente es menor y el combustible más susceptible al desarrollo de irradiación.

Manejo de Combustible en Berkeley (pág. 164)

La central de fuerza nuclear de Berkeley, que se está construyendo por A.E.I.—John Thompson para C.E.G.B., será una de las primeras centrales comerciales con equipo de cambio de combustible " en carga." Una serie de máquinas especiales—carga/descarga, vertedero, equipo de observación visual y de recuperación, mantenimiento de varillas de control y de actuadores—han sido evolucionadas por John Thompson Ordnance. Este artículo describe la operación de este equipo y trata brevemente con algunas de las exigencias especiales del cargado de combustible " en carga."

Seguridad de Buques Mercantes Impulsados a Fuerza Nuclear (pág. 169)

El Ministerio de Transporte ha promulgado recientemente una serie de recomendaciones para el diseño y la construcción de buques impulsados a fuerza nuclear. Se ofrece una sinopsis de las recomendaciones juntamente con una guía para su correcta interpretación.

Mecanizar Berilio (pág. 176)

La decisión de usar berilio como un medio de enfundadura de los elementos de combustible AGR ha creado una demanda por facilidades de mecanizado. El problema principal a ser vencido en mecanizar berilio es el de asegurar que todo el polvo producido durante la operación del mecanizado sea colectado y eliminado. En la fábrica de Whitley de Sir W. G. Armstrong Whitworth Aircraft, Ltd., una facilidad de 20,000 pies cuadrados (1858 metros cuadr.) ha sido construida especificamente para el mecanizado de berilio.

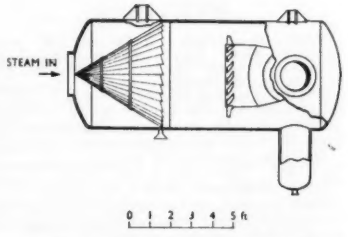
Technical Papers and Publications

THE INSTITUTION OF MECHANICAL ENGINEERS

Wetness in Steam Cycles. By B. Wood, M.A., M.I.Mech.E. (Head of Research and Development Department, Merz & McLellan.)

Wetness in steam is a problem that was first encountered in the days of reciprocating engines, became of considerable importance in the early turbine days, and eventually set a limit to steam pressures, unless temperatures rose accordingly. With the introduction of reheat into common use, its importance decreased. Now, with the reintroduction of saturated steam cycles for water-cooled reactors, as well as for geothermal steam plants, wetness and its removal have once more assumed significance.

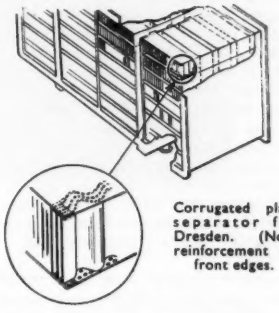
How important the effect of water in steam really is can be judged from a brief consideration of a saturated steam cycle. If wetness were to be limited to the nominal 14% usually tolerated, then (assuming high vacuum and no water-separating devices) the turbine inlet pressure would be limited to about 50 p.s.i.a.



The Shippingport steam separator, 1,300,000 lb/h 12% moisture 45 p.s.i.a. (Although the vanes collapsed at an early date, separation still occurred.)

One of the chief difficulties appears to be that the properties of wet steam are still but imperfectly understood. It has been realized for many years that wetness causes a loss of efficiency; in fact, Baumann's rule —every 1% of wetness lowers the stage efficiency by 1%—has been in use with only minor modifications since 1912. The loss is explicable as mainly mechanical, partly to the drag imposed on the steam, but mostly by the braking action of water droplets striking the back of the moving blades —capable, incidentally, of causing serious erosion. While the properties of saturated steam and boiling water are both well known, those of a mixture of the two are not, since the water may be present as a mist in uniform emulsion with the steam, as a separate stream of liquid, or in any intermediate form. A pressure drop equivalent to 10° F. in saturation temperature will cause 1% water to flash and, particularly at the L.P. end, the volume increase of a droplet (145 times, at 3 in vacuum) is violent. With the difficulty of visualizing clearly the exact behaviour of wet steam, it is scarcely to be wondered at that many of the early types of turbine drainage were not successful.

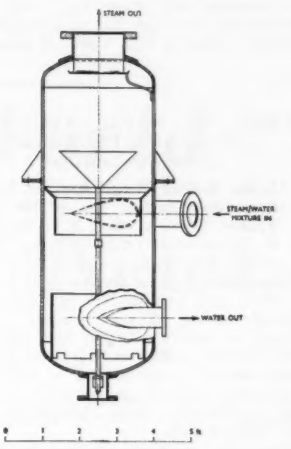
Irrespective of the efficiency—or otherwise—of turbine drainage devices, really high wetness, such as would be encountered in a nuclear station with fairly high pressure saturated steam as an initial condition, requires series interceptors, i.e. the whole steam flow must pass through a water-removal device, operating either on the cyclone principle or by surface effect (using the tendency of droplets, even in parallel passages, to be carried by eddies to the walls where, provided they are not re-entrained, they adhere and can be drained away). Corrugated plate eliminators are to be used at Dresden, where the wetness at crossover (10 p.s.i.a.) will be 12%, to be reduced to 5% (60% removal).



Corrugated plate separator for Dresden. (Note reinforcement on front edges.

With high wetness, it is necessary to use steam separators at the entry, as well as at interstage points. An efficient form is the tangential entry cyclone without vanes (designed by the author). This, on a 6-1 water/steam mixture at 220 p.s.i.a., gave 99.9% dryness with a pressure drop of about 3%, at a load of 100,000 lb/h.

Loss of efficiency and erosion are not the only troubles attributable to wet steam, since corrosion and erosion often go hand in hand. Corrosion often occurs in the wet region because of substances which are innocuous when carried in dry steam becoming dissolved in the wet region, the characteristic attack, with carbon dioxide, oxygen, etc., being violent cutting where water runs over metallic surfaces. In boiling-water reactors it is expected that some trouble may be caused by radiolysis of the water giving atomic oxygen. For this reason the inside of the Dresden stator casing and the drainage passages are protected with hard metal deposit. Although Shippingport operates from secondary steam, the stator casing is lined with 18/8 stainless steel, presumably to guard against possible contamination by leakage.



The author's tangential-entry cyclone design.

THE INSTITUTE OF FUEL

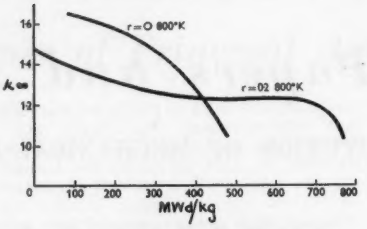
Nuclear Power for Ship Propulsion. By J. E. Richards, Ph.D., Wh.Sc. (Head of Atomic Energy Section, British Shipbuilding Research Association).

Main theme of this paper was the desirability of intensive work on plutonium-fuelled reactors. Following a general review of the economics of the nuclear ship, and the advantages and disadvantages of liquid-cooled and gas-cooled reactors, it was pointed out that the possible utilization of civil plutonium was of great interest because it might be freely available by about 1970. For this reason, the B.S.R.A. Atomic Energy team at Harwell had been making a study of this matter for the past year.

Civil plutonium, i.e., the material produced in a natural uranium graphite moderated reactor after irradiation to about 3,000 MWd/t, would contain about 80% Pu^{239}, 16% Pu^{240} (non-fissile), 4% Pu^{241}, and a negligible amount of Pu^{242}. The small Pu^{241} content did not contribute greatly to the initial reactivity, which depended mostly on the neutrons produced per fission in the Pu^{239} and the absorption of these in the Pu^{240}. In a large reactor, the equilibrium value would be about 1.35 so that, allowing one neutron to carry on the reaction, the amount of new plutonium generated in a small Pu-U^{238} system would be small. For this reason, B.S.R.A. studies had been confined to the burning of plutonium, ignoring regeneration. It could be shown that in a large reactor the calorific value of civil plutonium would be of the order of 830 MWd/kg. On a heat basis, 1 g of plutonium would be equivalent to 1.85 tons of oil fuel burnt in a marine boiler (18,500 B.t.u./lb with 88% boiler efficiency)

and, costing plutonium on its equivalence to U^{235} as an enrichment for natural U in an AGR reactor, it would be worth £5 per gram. Neglecting processing and fabrication costs, this would be equivalent to oil fuel at £2 14s per ton; since the present price of oil fuel was about £6 per ton, there was a chance for plutonium to provide low-cost fuel if the extraneous charges were not high.

To keep extraneous charges down, long burn-up was essential. Rough estimates of the variation of reactivity with burn-up on an infinitely large system could be made, and showed that the achievement of a flattened reactivity curve would depend on a high rate of absorption in Pu^{240} so that it would act as a burnable poison, reducing the initial reactivity and producing Pu^{241} which would extend the reactivity towards the end of the cycle. It might be possible to achieve a burn-up as high as 680 MWd/kg before the reactivity fell below $k_\infty = 1.2$. The achievement of a high rate of absorption in the Pu^{240} meant a high value of resonance



4. Variation of reactivity with burn-up, for epithermal components of 0 and 0.2. (Infinitely large reactor, 800°K, steel/plutonium ratio 66:1 (at.).)

absorption in the 1 eV region, and it was felt that this could be most easily achieved with graphite moderation. Graphite had the additional advantage of providing a large mass to act as a heat sink, and B.S.R.A. work was being confined to this.

It is considered that this fuel cycle will not only have economic promise but will have an advantage over the present HTGC concept in that an appreciable amount of structural material can be tolerated in the core; in particular, stainless steel canning can be used.

The work is complicated in that the cross-sections of the higher plutonium isotopes have not yet been determined very accurately. The initial work was carried out using the cross-sections due to C. H. Westcott and the next stage was to use a heavy gas model of the moderator and, using an analysis given by Wigner and Wilkins, calculate the thermal neutron spectron for homogeneous mixtures of graphite, steel and civil plutonium, the main purpose being to investigate the temperature coefficient of reactivity.

The work is far from complete but there are reasons for a certain amount of optimism, one being the fact that broadening of the plutonium^{240} resonance with increase in temperature gives a negative coefficient for the fuel of the order of 1.5×10^{-5}.

SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS (PHILADELPHIA)

A Marine Boiling Water Reactor Nuclear Propulsion System for 60,000 DWT Tanker. By V. A. Mize, B. G. Voorhees, F. Weinzimmer (Atomic Power Equipment Department, General Electric).

Costs within 10% of conventional shipping by 1963—and competitive by 1966—were forecast, on the basis of a study recently carried out jointly with the U.S. Maritime Administration (Office of Ship Construction), which showed a capital cost of $460/s.h.p. and a fuel cost of 3.9 mills/s.h.p.-h, foreseeable attainments being $385/s.h.p., and 2.65 mills/s.h.p.-h.

The costs are based on a study of the direct cycle boiling water system after comparison with an indirect cycle and particular attention has been paid to both stability and safety.

On the question of stability of operation, rigorous analysis of the reactor has shown that the maximum value of flux peaking due to ship motion would not exceed 140% of normal (the corresponding temperature rise at the fuel centre being 120°F (48.9°C)) for a vertical acceleration of 0.7g, i.e., at full power in the worst anticipated sea conditions.

In addition to analysis, a considerable amount of experimental work is under way on the effects of ship's attitude on heat transfer and hydraulic behaviour. Burn-out and hydraulic characteristics have been determined for a channel inclined at 45°, and no distinguishable change in burn-out heat flows have been observed, over a wide range of flows and exit qualities of steam, compared with a vertical channel. The inclined natural-circulation loop also exhibited the typical stability characteristics observed in vertical two-phase flow; at extremely high void fractions, instabilities were induced which could be damped by downcomer flow restrictions. In a further series of tests now under way, the simulated fuel rod is mounted in a pressure vessel which is rotated about an axis transverse to the axis of the fuel rod. This will provide experimental confirmation as to the effects of acceleration on boiling heat transfer and hydraulics.

As regards safety, analysis of a hypothetical accident involving a rupture of the main steam line has been made, based on extrapolation of the experience gained with the activity levels of the steam at Vallecitos. Allowing an operating time of 10-12 sec for automatic closing of the main steam valves, about 5c of N^{16} activity would be released, the dose to engine-room personnel being about 30 mrem. The accompanying release of activity from 10 leaking fuel elements would be less than 0.1c, with a corresponding I^{131} concentration of 10^{-5} $\mu c/cm^3$. These consequences would, in fact, be less of a hazard than scalding due to the steam. Dilution of the release from the engine room would ensure that the radiation exposure of the public would be less than the maximum permissible limits recommended internationally.

Preliminary studies have been made of a nuclear superheat cycle but it is stated that basic information is at present insufficient for a "real" design. The research programme under way has indicated that savings in capital costs of 10-15% may be achieved mostly by reductions in size of engine room equipment. Fuel cost gains on the other hand, may be offset by higher fabrication costs.

AEA

AERE Lib/L/1 (3rd Edition) Sources of Information in Atomic Energy. L. J. Anthony. (H.M.S.O., 6s.)

A very useful reference giving sources of information in the U.K. and overseas, with addresses of the various authorities. A separate section gives published sources of information including reports, reference books and periodicals (U.K. and international).

AERE Bib/127. List of Unclassified Reports and Papers Published by the Staff of the Isotope Division Since 1950. R. J. Millett, E. J. Wilson. (H.M.S.O., 5s. 6d.)

A useful publication for those requiring a quick reference to articles on isotopes. Indexed under authors, subjects and specific isotopes.

U.S. AEC

TID-7583. Chemical Processing of Irradiated Fuels. (Available from the Office of Technical Services, Department of Commerce, Washington 25, D.C., $4.50.)

A complete report of the proceedings of the symposium held by the A.E.C. on the chemical processing of irradiated fuels, from power, test and research reactors, at Richland, Washington, October 20 and 21, 1959.

AECL

AECL Publications. 1952-1959.

A list of publications by the staff of the Atomic Energy of Canada, Limited, classified under subjects, with an author index.

MEETINGS

March 30.—Institute of Metals (at Hoare Memorial Hall, Church House, Westminster, 10 a.m.), "Volume Increases in Fissile Materials on Neutron Irradiation," G. W. Greenwood. 2.30 p.m., Education session on "New Aspects of the Electron Theory of Metals," Dr. W. M. Lomer, general survey; Dr. V. Heine, recent experimental work; Dr. J. Friedel, electron structure of alloys.

March 31.—Institution of Electrical Engineers (at the I.E.E., 5.30 p.m.). The Kelvin Lecture, **"Cosmic Radiation."** Prof. C. F. Powell.

April 5.—Institute of Welding (Lecture Hall Community Centre, Farnham Road, Slough, 7.30 p.m.), "Shop Inspection of Welds."

April 5.—Institution of Electrical Engineers (Savoy Place, London, W.C.2, 5.30 p.m.), "Thermistors: Theory Manufacture and Application." R. W. Scarr and R. A. Setterington.

April 5.—Institute of Metals (Cadena Café, Cornmarket Street, Oxford, 7 p.m.), "Low Temperature Properties of Metals." H. M. Rosenberg.

April 7.—Institute of Metals (17 Belgrave Square, S.W.1, 6 p.m.), Symposium on Metallographic Techniques.

April 7.—British Institution of Radio Engineers (London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, W.C.1, 6.30 p.m.), "The Work of the B.S.I. in Relation to the Radio and Electronics Industry," H. A. R. Binney.

April 7.—Liverpool Metallurgical Society (The Library Department of Metallurgy, The University, 146 Brownlow Hill, Liverpool 3, 7 p.m.), "The Examination of Irradiated Fuel Elements," G. B. Greenough.

April 8.—Institute of Physics (47 Belgrave Square, S.W.1, 6 p.m.), "Nuclear fuel element inspection," R. S. Sharpe.

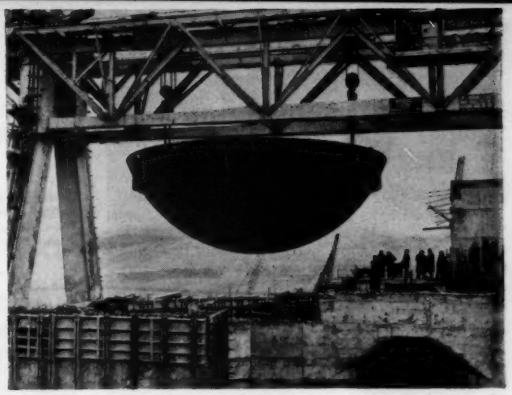
April 12.—Iron and Steel Institute and the Institute of Metals (Hoare Memorial Hall, Church House, Westminster, S.W.1, 10.30 a.m.), Symposium on "Direct Rolling Processes in Powder Metallurgy."

April 14.—East Midlands Metallurgical Society (School of Art, Green Lane, Derby, 7.30 p.m.), Reactor Metallurgy.

April 21.—Institute of Physics (Birmingham, The University), Joint Symposium on "The Training of the Industrial Physicist."

April 21.—The Institution of Mining and Metallurgy (at the Geological Society, Burlington House, Piccadilly, W.1, 5 p.m.), discussion on paper "Production of Thorium Metal" by A. R. Gibson and J. R. Chalkley.

April 25.—Royal Society of Health at Torquay, Radiation Section of Annual Congress.



(Left) The third course of the first reactor pressure vessel for Hunterston being lifted into place by a Goliath crane. The section weighs 240 tons. (Above) The bottom head and support course of the pressure vessel, which weighs 320 tons, is seen being carried towards the top of the biological shield. G.E.C. are building the station.

World News

International

THE SECOND REPORT of the European Nuclear Energy Agency of the OEEC has been published and is devoted more to recording work done, rather than proposals under consideration. The review covers an 18-month period and deals with the three projects started during this period, EUROCHEMIC, HALDEN and DRAGON.

MORE THAN 20 radiobiology research workers met in Vienna at the invitation of the IAEA during March to assist in integrating research programmes in selected fields and in the critical evaluation of research methods.

SAFE OPERATION recommendations are to be drafted by the IAEA for research reactors in member states. The first meeting of the Panel, on Safe Operation of Critical Assemblies and Research Reactors, met in February and will meet again this summer. The draft manual is expected to be ready by the end of the year.

THE BUDGET for 1960/61, £2.83 million, has been approved for the DRAGON project by the Board of Management. The budget includes £950,000 for the reactor plant, £910,000 for extra-mural work and £970,000 for the maintenance and work of the staff at Winfrith.

A REPORT has been issued by the OEEC on the measurement of environmental radioactivity in member countries. The report has been prepared by the Health and Safety subcommittee and surveys the national monitoring systems set up by European countries to safeguard populations. The report also lists the methods of measurement and frequency.

U.K.

INVITATIONS TO TENDER (due in at the end of May) for the construction of the Sizewell power station by the CEGB call for 550 MW and not 650 MW. Permission was granted by the Ministry of Power for a 650-MW station.

A SECOND NUCLEAR SUBMARINE will be ordered for the Navy this year according to Mr. C. I. Orr-Ewing, Civil Lord of the Admiralty. This statement was made in the House of Commons when the Navy Estimates for 1960-61 were moved. Mr. Orr-Ewing also said that "Dreadnought" would be launched in the autumn.

ANOTHER RESEARCH REACTOR of the AEA has begun operating. Situated at Aldermaston, the reactor HERALD will be used for research work requiring intense neutron beams and for irradiation-damage studies on reactor materials. It is a 5-MW Merlin-type supplied by A.E.I.-John Thompson.

IRRADIATION CURING of skins and hides has been successfully demonstrated on a tonnage basis. The investigations are being undertaken by the Egham laboratories of the British Leather Manufacturers Research Association in conjunction with the Technological Irradiation Group of the Isotope Research division of the AEA.

A PUBLIC INQUIRY into the proposal to build a power station at Oldbury in Gloucestershire will be held on April 12 according to an announcement by the Ministry of Power.

A NEW DIVISION for research reactors has been created at Harwell. It will be responsible for the operation, maintenance, safety and development for all research reactors, rigs, loops and auxiliary equipment.

STRESS RELIEVING has been successfully carried out on No. 2 reactor vessel at Berkeley. Constructed on site, the vessel is made of sections of 3- and 4-in. mild-steel plate and incorporates 2,500 ft of welds. The stress relieving was carried out by Electric Resistance Furnace, in one operation with a 2½-MW heating installation, and entailed heating to a minimum specified temperature of 575°C in 55½ hours.

THE NUCLEAR ENERGY SHOW, Atoms at Work, held in Bristol during March, was opened by Sir William Cook. It has already visited Sheffield and Bradford.

THE PRESSURE VESSEL for the first service machine for Hunterston has been installed in the G.E.C. Erith works. The machine will undergo a comprehensive series of tests at the workshop before installation.

HUMAN ENGINEERING and its relation to nuclear power stations has been studied for G.E.C. by a team of American experts. They have made detailed recommendations on the design of the control room for Sizewell.

SUITABLE SITES for two 2,000-MW coal-fired power stations have been found by the CEGB in Nottinghamshire.

Austria

A U.S. CONCERN, M and C Nuclear, will fabricate 36 MTR-type fuel elements for the swimming-pool type reactor ASTRA, at the Atomic Energy Society research station at Seibersdorf. The reactor is to be used jointly with the IAEA.

Inside the pressure vessel of No. 1 reactor at Berkeley where A.E.I.-John Thompson are now laying the graphite. In this view the first layer is nearing completion.

Australia

A REPORT by the Joint Committee on Constitutional Review has recommended that Parliament should be empowered by constitutional amendment to make laws with respect to the manufacture of nuclear fuels and the generation and use of nuclear energy and ionizing radiations. The Committee has also recommended alterations to the Constitution to include in the list of legislative powers, the power to make laws for the carrying on and promoting of scientific and industrial research.

TWO FACILITIES are being designed at Lucas Heights for using the gamma radiation from the spent fuel elements from the reactor HIFAR, for research in technological irradiation processes. The fuel elements have to be stored for 100 days before shipment to the U.K. One facility will consist of an aluminium tank filled with de-mineralized water and surrounded by heavy shielding. The second will be a 9-in. diameter stainless-steel thimble fitted into a storage block with an experimental space about 2 ft 6 in. long and 7 in. in diameter.

A CONFERENCE on the technological use of radiation is to be held at the University of New South Wales from May 23-25. The organizers are the Atomic Energy Board.

A REACTOR CONTRACT has been awarded by the AAEC to Advanced Technology Laboratories, a Division of American Standard, for the supply of a 10-kW UTR-10. The reactor will be used for physics experiments in the Commission's programme for the development of the HTGC. The reactor will also be available to all Australian universities for their own research and training programmes through the Institute of Nuclear Science and Engineering.

Brazil

THE FOUNDATION STONE for a uranium processing plant has been laid at Pocos de Caldas by the Governor of the State of Minas Gerais and the president of the Nuclear Energy Commission.

Canada

THE DANIELS-BOYD GENERATOR is to be developed by Winnett Boyd in association with Arthur D. Little Inc. of Cambridge, Mass. Outline designs of a 400 MW(e) unit envisage a spherical pressure vessel, uranium monocarbide fuel and helium coolant, producing steam at 1,050°F. 2,400 p.s.i. An unusual feature is the horizontal arrangement of the ceramic fuel elements combined with vertical coolant flow.

A RECORD OUTPUT of uranium was produced in Ontario during 1959, according to the Department of Mines. Nearly 12,400 tons worth $262.9 million were produced but by the end of the year only 13 mines were still operating, two having closed in 1959 and one in 1958. Another mine, owned by Canadian Dyno Mines, is expected to close in the province this year.

AMALGAMATION of the four Elliot Lake companies, Algom, Milliken Lake, Northspan and Pronto Uranium Mines is to take place and a new company, Rio Algom Mines, will be formed in June. The company will enter into a single master contract with Eldorado Mining and Refining, the Government purchasing agent, for the remainder of the existing contracts. The contract will call for the delivery of 34.4 million lb of uranium oxide.

Chile

AN ORGANIZATION Empresa Nacional de Electricidad, have reported that they have completed a three-year study for the installation of a pilot nuclear power plant at Mejiliones, north of Antofagasta.

Egypt

AN AGREEMENT has been signed by the Atomic Energy Commission with Noratom of Norway for the construction of a laboratory for the production of radio-isotopes.

West Germany

THE CONSTRUCTION of the nuclear centre at Heidelberg is well under way and when completed will house an institute " of international standing." It is expected to cost £1 million.

India

A TECHNICAL MISSION from the U.S. AEC are visiting India to investigate nuclear energy power requirements of the country with the Indian authorities. India is reported to be considering the early construction of a nuclear power station.

THE SITE for the proposed power station is reported to be between Bombay and Ahmedabad and most of the technical work has been completed and assessed. Economic assessment of alternative sites is at present under consideration.

Indonesia

A PROMISE has been made by Mr. Kruschev for the supply of a research reactor. The Russian premier made the promise on his recent tour to Indonesia when economic and technical co-operation agreements were signed.

Italy

AN INTENSIVE training course at Calder Hall is being given to Italian engineering staff who are to hold key posts at Latina. The training course includes a period at the Calder Operations School and a period of practical work on the Calder plant.

A RESEARCH REACTOR, the AGN 201, at the University of Palermo, went critical during February. The reactor was built by Aerojet-General of the U.S.

A CONTRACT has been awarded by the Government to Sylvania-Corning Nuclear of the U.S. for the supply of an improved type fuel element for use in the 5-MW heavy-water type reactor at the national research centre at Ispra. The new elements will be of the curved plate type, 18 plates to an element, of which 16 are active, containing 90% enriched uranium.

A NUCLEAR ENERGY CONGRESS will take place in Rome at the Palazzo dei Congressi from June 20-26. The congress is sponsored by the Comitato Nazionale Ricerche Nucleari.

Japan

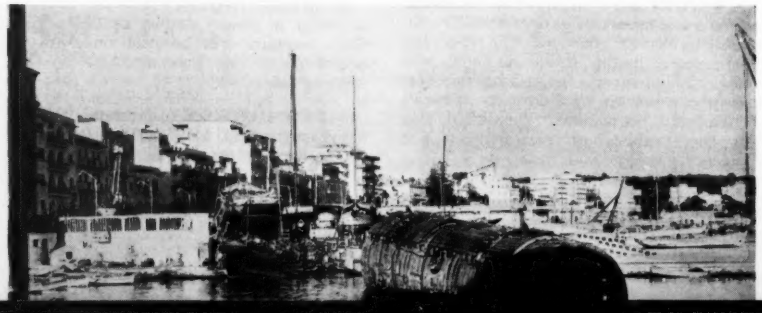
NEGOTIATIONS have been continuing with the U.K. AEA for the supply of fuel for the nuclear power station at present under construction at Tokai Mura by G.E.C. Dr. T. Ipponmatsu, vice-president of the Japan Atomic Power Company, recently signed a heads-of-contract agreement in London.

Netherlands

ANOTHER RESEARCH REACTOR, JASON (Hawker Siddeley) has been bought for the research centre at Petten. Construction work on the £50,000 reactor will start in June and the reactor is expected to begin operating in September. The installation is expected to cost another £50,000. Fuel will be supplied by the U.S. on a hire basis and will be 90% enriched uranium.

A BILL has been submitted to the Lower Chamber dealing with all aspects of nuclear energy. It proposes the establishing of a nuclear council to advise the Government and is expected to have special committees with specific responsibilities.

The first boiler for Latina in the harbour at Anzio, Italy. The boiler has been towed by sea-going tugs from the Marina di Carrara harbour.



New Zealand

URANIUM DEPOSITS have been discovered in Buller Gorge and an extensive investigation is being undertaken by the West Coast Company. The deposits are said to be widespread.

Puerto Rico

THE FINAL DESIGN of the nuclear portion of a demonstration power reactor plant, to be built in co-operation with the Puerto Rico Water Resources Authority, has been awarded by the AEC to General Nuclear Engineering. The reactor will be a 16.3 MW BWR.

Spain

A URANIUM PLANT at Andujar, Andalusia, was inaugurated on Feb. 14 by General Franco. The plant is expected to produce the uranium needed for Spain's future nuclear centres.

AN OFFER of 140 tons of uranium for sale has been made by the Government to the IAEA. The uranium will be in the form of concentrates or salts with 40 tons being available in 1960 and the remainder in the following two years. Price quoted is $19.80 per kg for concentrates and $24.80 for the trioxide.

EXTENSIVE PREPARATORY WORK is reputed to be under way in the Tobalina Valley in the Burgos Province for the installation of a nuclear power plant. The vice-president of Nuclenor S.A. has said that the power requirements for north Spain would increase considerably in the next 20 years and that nuclear power was the only practical solution.

Turkey

AN ISOTOPE LABORATORY is to be built at Istanbul University. The laboratory is a gift of the U.K. Government.

U.S.S.R.

FOUR HOLDERS of IAEA fellowships have graduated from the two-month training course on nuclear energy in agriculture at the Timiryazev Academy of Agriculture in Moscow. The holders of the fellowship are from Austria, Indonesia and two from Yugoslavia.

IT HAS BEEN REPORTED that a research reactor in Kiev has achieved criticality. No details are available.

THE CONTRACT for a scientific instrument exhibition by SIMA of the U.K. has now been signed. The exhibition will take place at the Polytechnic Museum in Moscow from June 18-29.

U.S.A.

THREE PROPOSED AMENDMENTS are to be published by the AEC to its licensing regulations to facilitate the issuing of construction permits and operating licences for civilian power reactors. The amendments are proposed with a view towards minimizing both delay and the degree of federal regulations involved.

ENROLMENTS in the first session of the International Institute of Nuclear Science and Engineering now Total 47 from 18 different countries. The AEC are sponsoring the Institute.

THE 15-TON CORE which will power the *N.S. Savannah* has achieved criticality at the Lynchburg laboratory of the Babcock and Wilcox Atomic Energy Division. The test of the core, which contains 32 fuel elements, containing 4.2 and 4.6% enriched uranium, was undertaken to confirm the design and engineering calculations. Testing took place in a tank 9 ft in diameter and 17 ft high and filled with more than 10,000 gallons of purified water.

TWO-THIRDS of the fuel loading programme at Dresden has been completed with 320 of the initial load of uranium fuel elements now installed. The reactor first went critical on October 15, 1959, after the first 28 elements had been loaded.

A NEW REACTOR for the Army to be known as OPERA (Ordnance Pulsed Experimental Research Assembly) is to be designed by Aerojet-General Nucleonics. Design specifications include a yield of more than 10^{17} fast neutrons per pulse and a pulse width variable down to 10μ sec measured at half-maximum.

A CONTRACT to conduct a study of the facilities required for testing an experimental, indirect cycle aircraft reactor has been awarded by the AEC to Blaw-Knox of Pittsburgh.

CRITICALITY WAS ACHIEVED by the Gas-cooled Reactor Experiment No. 1 of the AEC on February 23 at the National Reactor Testing Station, Idaho. The reactor is water-moderated and nitrogen cooled, generating 2.2 MW of heat but no electricity, and is part of the Commission's initial phase experiment for a mobile nuclear plant for the Army.

FURTHER DETAILS of the large particle accelerator being built for the Argonne National Laboratory have been released. The zero gradient proton synchrotron power supply will include a 68-ton steel flywheel, 13 ft in diameter and capable of spinning at 900 r.p.m. This flywheel will generate 117 MW for the 4,000-ton circular magnet and pulses of 117 MW will be delivered every four seconds. The facility is expected to cost about $29 million.

CONSTRUCTION of new facilities for metals and ceramics work at the Oak Ridge National Laboratory will be undertaken by Henry C. Beck of Atlanta. The facilities are expected to cost $4.8 million.

THE MANUFACTURE and design of the nuclear instrumentation for the AEC's Hallam Nuclear Power facility will be undertaken by General Electric according to a contract signed with Atomics International, the main contractors for the 75 MW sodium-graphite power plant.

A FIVE-YEAR PROGRAMME on high-energy research, costing $300 million, has been asked for by the AEC. The programme is to probe new fields in nuclear energy and includes the construction of two new accelerators.

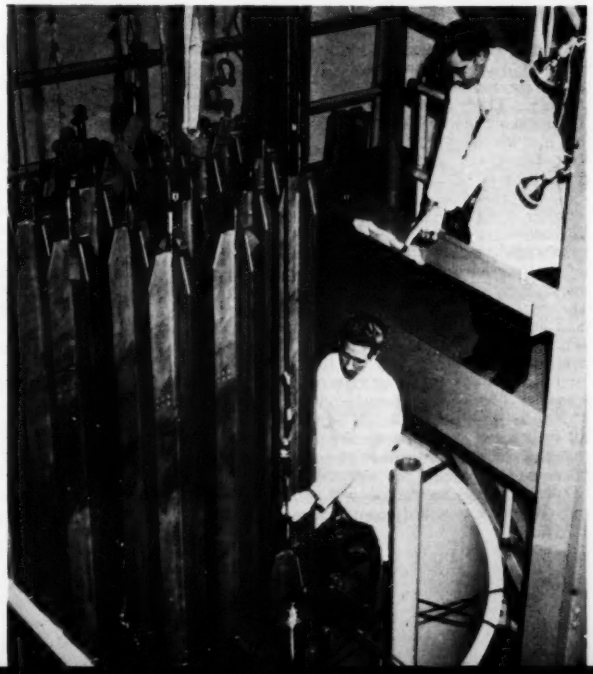
FIVE ELECTRIC UTILITIES are studying the possibility of building a plant to process used fuel elements in conjunction with a chemical company. A report will be prepared within the next six months.

POWER FROM ISOTOPES is the basis of a $2¼ million contract awarded to the Martin Company for a continuation of their development of SNAP-3 power sources for space vehicles.

WASTE DISPOSAL SITES off the California coast are to be investigated under an AEC contract by Cleveland Pneumatic Industries. Two sites, the older used since 1946, will be surveyed and photographed at six-monthly intervals.

ANOTHER SUBMARINE, powered by a reactor, has broken through the ice near the North Pole. The *Sargo*, submerged in the Bering Sea, off Alaska, and after travelling 2,744 miles under the ocean, surfaced through the ice on February 12.

AN ACCIDENT OCCURRED in November at the Oak Ridge National Laboratory which resulted in some four acres, including roof areas, being contaminated by scattered plutonium. A small chemical explosion was the cause, but no one was injured. Decontamination of the area was completed during February.



Assembly of the core for the reactor to power the *N.S. Savannah* at the Babcock and Wilcox works in Lynchburg.

NEW BOOKS

Materials for Nuclear Reactors. Edited by B. Kopelman. (411 pp., McGraw-Hill Book Co., Ltd., 93s.)

This book conforms in many ways with what we have come to expect of American books on technological subjects, being beautifully produced, and lavishly illustrated. It has also about 30 authors and tries to be many things to many men. Some of the authors are obviously so full of enthusiasm in their own work that they find it hard to separate what is of general interest from what is important only to their own particular processes.

According to the editor the book is meant to be "a bird's eye compendium of the advantages and of the limitations of materials as fuel elements, moderators, coolants, shields, and structure formers." Also "it is hoped that this book will be useful not only to those now active in this specialized field but also those just entering it as well as those in related fields seeking a general familiarity with the subject." These aims are wholly admirable, but only a detached referee, not himself engaged in the hurly-burly of production or development, could fulfil them.

There are 10 sections covering the range of topics. The first gives an outline of "Extractive metallurgy of special reactor materials" in 30 pages. The first 10 pages go into the extractions of uranium. It is quite a good survey, but one is left to wonder why anyone trying to get a general idea in a few pages, should want to know the sieve mesh sizes and tap density of fused Dolomite used for lining somebody's reduction bomb, or the temperature and concentration of acetic acid in a particular washing process.

The chapter on Thorium gives four lines to the direct oxide reduction process which has operated successfully in this country for 10 years. Zirconium gets extensive attention as one would expect. Fuel element material get chapters 2, 3 and part of 5 as well as some attention in chapter 4 on fuel element testing and chapter 7 on fuel processing. There is a certain amount of duplication by the different authors as well as some disagreement of opinion.

The sections on physical and mechanical properties of the metals uranium, thorium, zirconium and beryllium follow conventional lines. This information is, of course, readily available in the literature. The picture of uranium oxide fuel elements, which is of much current interest, is not quite so satisfactory. There are 17 pages on the subject in chapter 2 under Fuel Materials, 4 pages by a different author in chapter 3 under Ceramic Cores, none in chapter 4 under Fuel Element Testing techniques, and none in the otherwise extensive and thorough chapter 5 on Radiation Effects. Magnox fuel elements get five lines in passing.

Materials used in the current generation of pressurized water reactors receive the most attention; even here one is left with the impression that there is too much detail and not enough synthesis for either the man who looks for general knowledge or the man who thinks of going into the fuel business, and not enough to be of help to the man engaged in design or manufacture.

Any of these people would be best advised to read some of the excellent survey papers on the subject presented during the last Geneva Conference for the broader view while the expert on the job will still have to rely on the specialized report literature.

The book contains a commendably large number of references with good representation of non-American sources. S.G.B.

Fundamental Aspects of Reactor Shielding. By H. Goldstein. (416 pp., Addison-Wesley Publishing Co. Inc., 66s. 6d.)

Dr. Goldstein's book, first written in 1956 for the U.S. AEC, has now been generally published in an expanded version. Despite its age (as books go nowadays) it should be of interest to three classes of reader; the scientifically minded layman, the nuclear engineer, and the specialist in shielding. The first two classes will, of course, avoid most of the mathematics in the text.

Unlike other dangers, radio-activity cannot be seen (except by means of instruments) and the general public regards the dangers from exposure with a somewhat emotional attitude. By reading this book, especially the first three chapters, the "scientific" layman can obtain a background of information which he could use to reduce the general public's apprehension.

The nuclear engineer, i.e., one who is engaged in designing equipment for use in or with nuclear reactors, will be able to understand the work of the shielding expert and the effects of radiation on the materials which he specifies for his equipment.

The first four, or introductory, chapters deal briefly with the biological effects of radiation, the sources of neutrons and experimental facilities available in the United States in 1956. The two most important chapters are concerned with the attenuation of gamma rays and the reduction of fast neutron penetrations. The author concentrates his attention on these two types of radiation, because any shield which is effective against them will also be effective against other forms of radiation from a reactor.

Various methods of calculating attenuations are outlined, together with their limitations, but the author keeps to his title and omits a number of subsidiary problems such as holes in shields, shield heating and induced radiations. These chapters are supplemented by five useful appendices and are well referenced.

The book is clearly written, easily read, and should become as authoritative a treatise in its own field as has Glasstone and Edlunds' book on Reactor Theory.

H.C.S.

Windscale—Problems of Civil Construction and Maintenance, by Stewart Sinclair, M.I.C.W. (136 pp., 46 illus., George Newnes, Ltd., Tower House, Southampton Street, London, W.C.2. 25s.)

Windscale, which has been referred to as "a monument to our inefficiency," yet which has done such valuable work, is here surveyed from the point of view of a civil engineer. Little is said on nuclear matters, but there is a first-hand account of construction which commences with the site clearance of the old TNT factory, and reviews the construction of the pile buildings with their unique chimneys, and some of the interesting problems encountered, amongst which were the use of a Bailey Bridge for construction of the pile tops, and the organization for simultaneous internal and external work on the chimneys. Remedial work for the charge faces is covered, as are the difficulties encountered in "Operation Blowhard," which involved drilling 5-in. diameter holes through reinforced concrete, with minimum dust, under bad working conditions. Day-to-day maintenance problems are also dealt with, including the famous repair to the scanner gear under radiation conditions. Based on a number of papers on civil engineering problems encountered, this book will be found of absorbing interest even to those who have no knowledge of nuclear problems.

Kempe's Engineers Year Book. Edited by C. E. Prockter, M.I.E.E., M.I.Mech.E., under the direction of B. W. Pendred, M.I.Mech.E., M.I.S.I. (65th edition, 2,738 pp. (2 vols.). Morgan Brothers (Publishers), Ltd., 28 Essex Street, Strand, W.C.2. 87s. 6d.)

"Kempes" is an institution in the engineering field and there can be few engineers who can remember a time when it did not exist. As an engineering reference book, therefore, it requires no introduction. This year it is good to see that the section on nuclear power has been completely rewritten and brought up to date by Mr. R. Vaux and Professor J. M. Kay. Some 18 pages briefly introduce the physical basis of nuclear reactors, and pass on to core calculations, types of reactor and a consideration of fuels and use of isotopes with a brief section on the maximum permissible levels of radiation.

Other new sections include electronic engineering and pre-stressed concrete, while additions have been made in a number of other portions, including base-exchange water softening and performance of refrigerants. Other sections, including British Standards, have been revised and brought up to date.

Books Received

Lectures on Nuclear Theory. By L. Landau and Ya. Smorodinsky. Pp. 108. Translated from the Russian. Plenum Press, Inc. (New York). Chapman and Hall, Ltd., 37 Essex Street, London, W.C.2. 45s.

Experimental Nuclear Physics (Vol. 3). By E. Segre. Pp. 811. Chapman and Hall, Ltd., 37 Essex Street, London, W.C.2. 184s.

Physics of the Atom. By M. Russell Wehr and James A. Richards, Jr. Addison-Wesley Publishing Co. Inc., 10-15 Chitty Street, London, W.1. 49s.

Chemistry for Engineers. By Edward Cartmell. Pp. 172. Butterworths Scientific Publications, 4 and 5 Bell Yard, London, W.C.2. 25s.

Process Integration and Instrumentation. Pp. 204. Published by British Electrical Development Association, 2 Savoy Hill, London, W.C.2. 8s. 6d.

Thorium Production Technology. By F. L. Cuthbert. Pp. 303. Addison-Wesley Publishing Co., Inc., 10-15 Chitty Street, London, W.1. 42s.

Non-Newtonian Fluids, Fluid Mechanics, Mixing and Heat Transfer. By W. L. Wilkinson. 138 pp. Pergamon Press. 37s. 6d.

Liquid-Metal Heat Transfer Media. By S. S. Kutateladze, V. M. Borishanskii, I. I. Novikov and O. S. Fedynskii. 149 pp. Consultants Bureau Inc., 227 West 17th Street, New York, 11, N.Y. $22.50.

Encyclopedic Dictionary of Electronics and Nuclear Engineering. By Robert I. Sarbacher. 1,417 pp. Sir Isaac Pitman and Sons, Ltd. £8.

Exploding Wires. Edited by William G. Chace and Howard K. Moore. 373 pp. Plenum Press Inc., 227 West 17th Street, New York, 11, N.Y. 76s.

Health Physics in Nuclear Installations. Symposium organized at the Danish Atomic Energy Centre of RISO, 25-28 May, 1959, by OEEC, ENEA, OECE and the Danish Atomic Energy Commission. 410 pp. Publications de L'O.E.C.E., 2 rue Andre-Pascal, Paris XVIe. 37s. 6d.

Personal

Mr. M. J. Cahalan.

Mr. C. J. O. Garrard.

Dr. H. K. Cameron.

Dr. K. J. Wootton.

Mr. M. J. Cahalan as technical supervisor of Thorium Limited. The board is **Mr. R. W. Wright,** chairman, **Mr. J. R. Poole** and **Mr. J. R. Robinson** of Rio Tinto, and **Mr. C. Benson Branch, Mr. R. H. Gregory** and **Dr. J. D. Head** of Dow Chemicals.

Dr. K. J. Wootton, general manager, Erith Works; **Mr. C. J. O. Garrard,** deputy general manager, Erith Works; **Dr. H. K. Cameron,** manager, Atomic Energy Division, Erith, of G.E.C.

Mr. R. Turner to the board of Powell Duffryn Carbon Products as deputy chairman. **Mr. F. W. Stokes** becomes general manager.

Mr. W. L. Mather as chairman of Mather and Platt.

Mr. P. Wrightson as vice-chairman and managing director of Head Wrightson and **Mr. G. P. Davidson** as managing director of Head Wrightson Processes.

Mr. E. M. Whitaker as assistant to the commercial director of AEI (Woolwich).

AEA appointments are: **Mr. W. F. Wood** as acting division head of the new research reactor division at Harwell; **Mr. R. F. Jackson** as chief engineer, AERE; **Mr. B. S. Smith** as head of the health physics division, AERE; **Mr. P. G. Oates** as chief personnel officer at AERE; **Mr. H. J. Grout** as chief engineer, Winfrith, and **Mr. B. T. Price** as head of the reactor development division, Winfrith.

Mr. A. B. Vickery as managing director of Brookhurst Igranic.

Mr. D. McDonald to the board; **Mr. C. Phillips** as divisional director, works, of Bruce Peebles.

Mr. T. P. Everett as sales director of Hawker Siddeley Brush Turbines.

Mr. A. E. Frost as treasurer of I.C.I. **Mr. H. A. D. Perry** and **Mr. L. D. Stewart** as joint managing directors.

DRAGON appointments are: **Mr. R. K. Andresen** (Norway), head of administration; **Mr. G. Franco** (Euratom), chief engineer; **Mr. S. B. Hosegood** (U.K.) and **Mr. R. Tron** (Euratom) deputy chief engineers.

Mr. J. Leckie as second secretary of the Board of Trade. **Mr. G. H. Andrew** becomes second secretary (overseas).

Mr. J. Carson, chairman; **Sir Allan Lockhart,** managing director; **Mr. G. T. T. Rheam,** general manager, sales and engineering; **Mr. A. H. Kynaston,** general manager, production of the new Stewarts and Lloyds Pipework Engineering Division.

Mr. F. Harman to the board of Tangyes.

Mr. D. H. Roberts as secretary of Lancashire Dynamo Holdings.

Lord Chandos as president of the Locomotive and Allied Manufacturers Association.

Mr. F. N. Yates as commercial manager of Seton Creaghe Engineering.

Mr. W. Padley to the board of Metal Industries.

Group Captain E. A. Warfield as general manager of the Avica Group.

Mr. A. C. Green, works manager; **Mr. J. R. Erskine,** chief engineer and **Mr. S. J. Arliss,** production engineer of the newly formed Avel-Toroid division of Aveley Electric.

Mr. F. G. Pentecost to the board of Albright and Wilson.

Mr. K. R. Sandiford as general manager of Hagan Controls.

Mr. C. C. Birch as assistant managing director of Guest Keen and Nettlefold (Midland).

Mr. C. H. Chichester Smith as managing director of Fairey's and **Mr. C. C. Vinson** and **Mr. L. S. Dawkins** to the board.

Mr. J. Samuels as works director in charge of production of Winston Electronics.

Mr. W. J. Jeavons to the board of John Thompson-Kennicott.

Mr. D. Latham to the board of Edwards High Vacuum.

Mr. T. D. H. Andrews as managing director of Dowty Nucleonics.

Mr. J. P. V. Woolam, Mr. G. Gresle Farthing and **Mr. R. W. Rutherford,** chairman, to the board of the newly formed Chemical Works Projects.

Mr. R. F. Jackson.

Dr. A. C. Hall.

Mr. C. H. C. Smith.

Mr. E. M. Whitaker.

Overseas

Mr. A. Lilar (Belgium) has been elected chairman and **Mr. C. van den Bosch** (Belgium) vice-chairman of the IAEA Panel on Liability for Nuclear Ships. The U.K. representative is **Mr. R. A. Thompson** of the Atomic Energy Division of the Ministry of Science. **Mr. A. H. Kent** of the Ministry of Transport has been named as an alternative and adviser.

Dr. C. Starr as president of Atomics International.

Dr. A. C. Hall as vice-president, engineering, of The Martin Company, Baltimore, and **Dr. W. L. Whitson** as director of the advanced programmes division.

Dr. G. C. Dalton as a director of the Lucas Heights research establishment of the Australian Atomic Energy Commission.

Mr. R. E. Wilson to the AEC's General Advisory Committee.

Dr. W. K. Stromquist as chief of plants systems engineering of the nuclear division of Alco Products.

Mr. S. Oestreicher as sales manager, AMF Atomics division.

Obituary

Nuclear Engineering regrets to report the deaths of the following:

Mr. George Wood, vice-president of Thos. W. Ward, Ltd., on March 14.

Mr. D. A. V. Rist, managing director of Rist's Wires and Cables, on February 25.

Mr. B. J. Edwards, a former director of Pye, on February 16.

Sir Edward Crowe, formerly a director of W. T. Henley's Telegraph on March 8 at the age of 82.

Awards

Sir Geoffrey Taylor the Kelvin Gold Medal by the Institution of Civil Engineers.

Prof. R. F. Mehl the Institute of Metals (Platinum) Medal for 1960.

Prof. N. J. Petch the Rosenhain Medal for 1960.

Dr. M. Cook and **Mr. E. Swainson** the W. H. A. Robertson Medal and Premium for 1959.

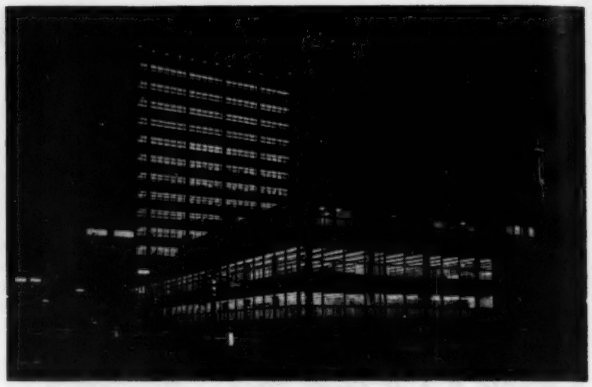
Retirements

Mr. L. E. Mather as chairman of Mather and Platt.

Mr. C. J. Carter from the board of John Thompson-Kennicott.

Mr. W. F. Osborne as production director of fibre division, I.C.I.

Industrial Notes



The new headquarters of the Wakefield Castrol Group in Marylebone Road, London. The 15-storey high building is of reinforced concrete frame construction with a 12-storey glass tower. The tower is floodlit internally through opaque, green glass panels which surround the building beneath windows on each floor.

G.E.C. have been awarded a further contract by the AEA for electric furnaces for use in the production of plutonium metal. The order is for reduction and fluorination furnaces. The fluorination type is rated at 10 kW and is of the horizontal front-loading type with muffles with the inner surface of the muffles and doors platinium lined. The reduction furnace is rated at 50 kW and is of the bell-type design.

Two of the original nuclear consortia, who last September announced that they would collaborate on future schemes have now decided to terminate the agreement. In a joint statement, **General Electric-Simon Carves Atomic Energy Group** and **Atomic Power Constructions** say that they have not found it possible to agree on the scope and functions of a new organization to give effect to the plans to collaborate in the design and construction of nuclear power stations and for the joint submission of tenders for Dungeness.

William Bain are to supply 1,100 tons of structural steelwork for the main research buildings, laboratory and control room for the thermo-nuclear device, ICSE, which will be built at the new CTR headquarters at Culham.

Flame cleaning at Aldermaston is being carried out by **British Oxygen Gases,** Saffire, oxy-acetylene equipment. Four chimneys, each 82 ft high and covering 8,000 sq ft and an acid storage plant of 5,000 sq ft are among the structures being cleaned.

AEI have delivered the first stator for the four 85 MW turbine generator sets for Berkeley. Each generator will supply 50 c/s 3-phase alternating current at 11,800 volts with cooling by hydrogen which is fan-circulated at 30 p.s.i.g. The stators weigh 118 tons and are 21 ft 5 in. long, 12 ft 10 in. wide and 13 ft 1 in. high. AEI have recently been awarded a Canadian contract for the supply of two 300 MW steam turbine-generator sets for the Lakeview power station near Toronto.

A contract worth £145,000 has been awarded by the AEA to **Mitchell Engineering** for the supply and erection of civil engineering works, steam generation plant, buildings, an oil-tank farm and ancillary equipment for Windscale. Work is expected to be completed by October this year.

The Board of Trade have announced certain export licensing changes which includes the removal of control on photo-multiplier tubes and the redefining of liability on cathode-ray oscilloscopes, electronic cathode-ray tubes and vacuum tubes, boron compounds and mixtures and certain metal working machines.

E.M.I. have signed an agreement with **Fairbanks Whitney** of New York for the sale of their range of electronic equipment, including nuclear instruments, in the U.S.

Firth Cleveland Steel Strip announce that they now specialize in the production of high carbon steel strip.

Stewarts and Lloyds have formed a new division, **Pipework Engineering,** to be responsible for the making and marketing of all forms of manipulated pipework. Headquarters will be at Broad Street Chambers, Birmingham 1, and 41 Oswald Street, Glasgow.

Head Wrightson have signed an agreement with the **Belco** division of **Bogue Electric Manufacturing,** U.S., which will enable them to design and build water treatment and trade waste disposal plants throughout the world, excluding the U.S. **Head Wrightson Processes** will be responsible for the design and manufacture of the equipment at their headquarters at Yarm-on-Tees.

Co-operation agreements for the manufacturing of klystrons, travelling wave and power tubes are announced between **English Electric Valve** and **Eitel McCullough** of the U.S. The agreement will allow early production by the companies of each other's ranges.

Chemical Works Projects is the name of a new company formed by **P.G. Engineering, Humphreys and Glasgow** and **Simon Carves** to supplement their normal activities by undertaking overseas projects for chemical and fertilizer work.

Postgraduate courses at the **Imperial College of Science and Technology** for 1960-61 include Nuclear Technology (Chemical) and Nuclear Power.

Further courses and symposiums in the U.K. and abroad:—

Symposium on nuclear reactor containment buildings and pressure vessels, **Royal College of Science and Technology,** Glasgow, May 17-20. Course on nuclear reactor technology, **Bradford Institute of Technology,** April 25-June 3. International discussion on nuclear power works, **Elektrotechnischer Verein Oesterreich,** Vienna, April 27-29. Course on nuclear energy law, **Centro Internazionale di Studi e Documentazione Sulle Comunita' Europee,** Milan, March 7-April 13. Course on the structure of metals and alloys, **Battersea College of Technology,** April. A short course on nuclear power plant design in collaboration with APC and Babcock and Wilcox at the **Northampton College of Advanced Technology,** May 2-13.

Elliott Nucleonics have been awarded the contract for the reactor flux scanning equipment for Trawsfynydd by **Atomic Power Constructions.** The equipment comprises 50 units and is used to measure the neutron flux distribution through the reactor in vertical and horizontal axes.

The International Pipes and Pipelines Exhibition is to be held at Earls Court from May 30 to June 2.

The Royal Society will celebrate its tercentenary year from July 18-26.

E.M.O. Instrumentation have recently concluded an agreement with **The Barden Corporation** of the U.S. in connection with precision bearing manufacture.

Sales of electrodes manufactured by **G. D. Peters** will in future be handled by Weldcraft, Ltd. Trade names will remain unchanged.

Murex Welding Processes, Ltd., are holding an exhibition at the works of Specialloid, Ltd., in Leeds, April 5-9.

Two simple draft standards for end suction and horizontally split-casing pumps have been produced by the **Engineering Equipment Users Association.** The drafts deal with overall fixing dimensions only.

New addresses are:—

Telemechanic are now at Brokenford Lane, Totton, Southampton. Tel: Totton 3666.

Startrite Engineering have moved to Darland Hall, Star Mill Lane, Chatham. Tel: Gillingham 50151.

Simmons and Hawkers are now at Central Way, North Feltham Trading Estate.

Andrew Fraser have moved to 64 Vincent Square, London, S.W.1. Tel: Victoria 6736.

West Instruments have opened a new sales and service department at White Buildings, Fitzalan Square, Sheffield. Tel: Sheffield 22461.

AEI have a new product department for semiconductors at 155 Charing Cross Road, London, W.C.2.

Processes and Equipment

For further information on any item please enter the relevant number on the Reader Service Card enclosed with this issue and forward the card to the address given.

D.A.M.E.

The Data Acquisition and Monitoring Equipment developed by de Havilland Propellers, Ltd., is a significant step towards complete integration of control systems for the commercial market. Designed for maximum flexibility, it is adaptable to a wide variety of industrial applications, either for simple data gathering, or for the analysis of data and, if required, subsequent executive action.

For simple data gathering, incoming electrical signals are measured to $\pm 0.1\%$ and printed-out at a rate of 1/sec, either by electric typewriter, to form a log sheet, or transferred to magnetic tape, or punched tape or cards for computation.

Monitoring is carried out by converting the incoming signals to digital information, and presenting them as a percentage deviation from a predetermined value. When any channel is outside the limits, action can be taken in one or more ways; by printing the logged result in red; by alarms or "fail" lights; by automatic initiation of a predetermined emergency programme. D.A.M.E. can also initiate a sequence of executive actions, monitoring the results; it can inject signals into a system and measure their effect, for checking purposes. Programmes, which of course are "tailored" to suit particular requirements, can be initiated manually or automatically.

The equipment, transistorized for maximum compactness, is housed in rack units, a single 6-ft rack housing a 60-channel unit without executive action, while a 300-channel equipment with executive facilities would be housed in three such racks. The controls consist of a telephone dial, an on-off switch, and a cancelling key. Display comprises a 3-digit channel identification, a display of the test result (with + or − sign) and a red "fail" light.

(De Havilland Propellers, Ltd., Watford, Herts.)

1284

D.A.M.E. equipment, showing control (above) and racks (below).

Large Scintillation Crystals

The difficulties in producing and activating plastics scintillation fluors in large sizes are considerable but, for high energy radiation detection and for human body count, large crystals are very desirable. The Single Crystal Division of Semi-Elements, Inc., is now able to produce them in sizes up to 400 lb. in the rough, which will permit machined lengths of up to 24 in., and diameters of 16 in., or more. The manufacturers state that this is by no means a maximum limit and, should the demand for larger sizes arise, these can be produced and, in fact, they would be glad to consider a scintillation fluor "that could encapsulate a body entirely."

(Semi-Elements Inc., Saxonburg Boulevard, Saxonburg, Pa.)

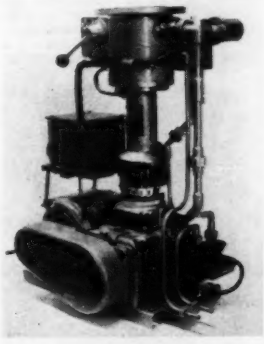
1285

Large cast scintillation crystals.

Automatic Vacuum Pump

Laboratory and industrial users are now offered single-lever control of a vacuum unit which is fully protected against power failure, falling water pressure, or accidental stoppage. The operating lever has four positions: rough pump, fine pump, isolation, air admittance; magnetic valves with time lags ensure correct operation. If, for example, the supply should fail and the unit stop during fine pumping, the backing (rough) line is isolated and air is admitted, preventing oil being sucked from the diffusion pump into the backing line. When the supply is restored, the air admittance valve closes, and the isolation valve opens, after a time lag to allow the roughing line to be pumped down so that the atmosphere does not come into contact with hot oil in the diffusion pump, while the vacuum in the vessel is maintained.

The unit is supplied in two sizes; 23 litre/sec and 100 litre/sec at 10^{-4} mm Hg, the ultimate being better than 5×10^{-6} mm Hg.



N.G.N. automatic vacuum pump unit.

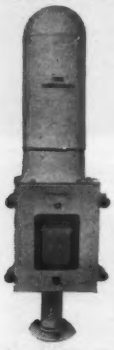
The backing pumps are gas ballasted to allow the evacuation of chambers containing condensable vapours, and liquid air traps can be provided if necessary.

(N.G.N. Electrical Ltd., Avenue Parade, Accrington, Lancs.)

1286

Background Recorder

Continuous monitoring and recording of background gamma radiation—essential information for health physics personnel—is provided by the Gammagraph 65A, a totally enclosed weather-proof unit operating independently of electricity supplies, and suitable for remote areas. An 18 in. ionization chamber and a new transistorized electrometer drive a rugged 1mA recorder (full scale as low as 10^{-12} amp) the trace being observable through a glass panel without opening the instrument. The recorder is clockwork driven and, since all equipment (with the exception of one electrometer valve) is transistorized, operates for one month on a built-in 12V 40 Ah car battery. Three ranges enable radiation levels from background level to 10 mr/h to be recorded, its sensitivity being nearly quality independent from 60 keV to 2 MeV, and zero stability is claimed to be better than 2% full scale on any range for any one month.



The "Gammagraph"

The unit is 9 in. (22 cm) diameter, and 30 in. (76 cm) high, the weight being approximately 70 lb (32 kg).

(Electronic Instruments, Ltd., Richmond, Surrey.)

1287

Smaller Cooling Towers

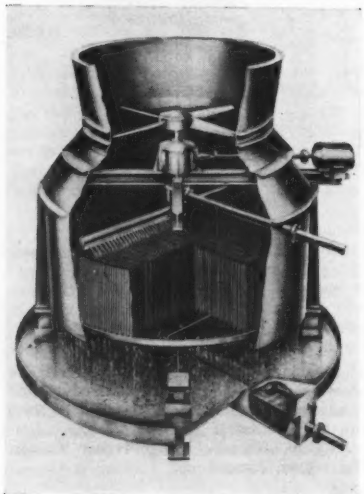
Considerable reduction in size and weight is achieved in a new range of Thermotank induced-draught cooling towers, announced in 12 standard sizes up to a capacity of 90,000 gal/h, the largest being only 20 ft diameter by 12 ft high, and weighing only 9¼ tons.

Main factor in this size-reduction is the use of a new fill, developed by Carl Munters, of Sweden, for which Thermotank have exclusive licence arrangements in a number of countries. This fill, said to occupy only one-fifth of the space of conventional wooden slats for the same performance, is made from alternate flat and corrugated sheets of a plastics-impregnated cellulose material, presenting a very large surface area, combined with high "wettability" without mechanical weakness or tendency towards chemical degradation.

(Thermotank, Ltd., Helen Street, Glasgow, S.W.1.)

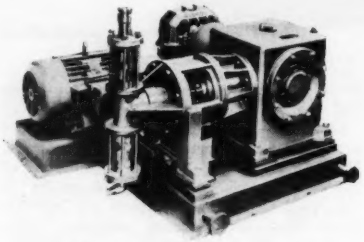
1288

Thermotank cooling tower



Metering Pumps

The Metricon range of pumps is designed for adding solutions at a fixed rate, for process work, boiler water treatment and similar purposes. Of the reciprocating type, the pumps have a fixed stroke, with several different piston diameters to vary the delivery. Either single or double pumps may be obtained; these may either "double-up" for increased capacity, or inject two different solutions at a predetermined ratio, depending upon the respective piston diameters. Variable-speed gears for hand or automatic control can also be supplied.



Metricon metering pump unit

The pumps themselves may be arranged for any type of corrosive liquid or suspensions, and stainless steel, ebonite, glass, and ceramic valves are available, according to duty. The units are made in sizes from 40-520 gal/h (simplex) and 80-1,040 gal/h (duplex), maximum working pressures varying from 250-3,000 p.s.i.

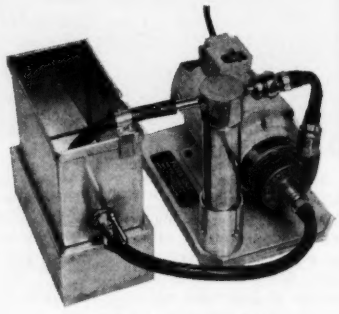
A plant hire scheme has been introduced to enable experimental work to be carried out by companies on their own premises, and assist in determining their own specific needs.

(Metering Pumps, Ltd., 21 The Mall, Ealing, W.5.)

1289

Filter for Cleaning Fluid

The effectiveness of ultrasonic cleaning has led to its widespread use, particularly where earlier methods prove too costly to obtain the desired results. A further contribution to the economy of ultrasonic cleaning is the production of a filter unit to remove the suspended dirt from the cleaning solution while in operation, thus saving both the cost of frequent solution renewal and the time taken in operation. Continuous filtration of the solution can be carried out with a unit consisting of a stainless-steel centrifugal pump which removes the fluid from the bottom of the bath and replaces it at the top, after passing through a filter. This, of the sintered (porous) stainless-steel type, can be obtained in eight grades, the finest size having a throughput of 8 gal/h and removing particles down to 2μ. Filter elements can be changed in less than 1 min. Overall dimensions of the unit are 12 in. × 6½ in. × 10 in. high, and the motor loading is 200W. Interconnections are of extruded nylon.



Dawe filter for cleaning fluid

(Dawe Instruments, Ltd., 99 Uxbridge Road, London, W.5.)

1290

BRIEFLY . . .

Additions to the Philips range of "Thermocoax" miniature thermocouple wires are announced by **Research and Control Instruments, Ltd.,** Instrument House, 207 King's Cross Road, London, W.C.1. **(B 100)**

New developments in hermetically sealed plugs and sockets of miniature size are given by **Electro Methods, Ltd.,** Caxton Way, Stevenage, Herts. Up to 50 contacts per pair can be arranged. **(B 101)**

ALAG, a synthetic aggregate with a chemical affinity for high-alumina cement (Ciment Fondu) is being marketed by the **Lafarge Aluminous Cement Co., Ltd.,** 73 Brook Street, London, W.1. Dense, hard, and heat-resistant, Ciment Fondu/ALAG concrete gives a compressive strength of 13,000 p.s.i. after 24 hours. **(B 102)**

Precision seamless balls in nylon, P.T.F.E., acrylic and polythene plastics, in sizes from 3/32 in. to 2½ in., for a wide variety of purposes from chemical milling to floats are offered by **Insley Industrial Supply Co., Ltd.,** 21 Poland Street, London, W.1. **(B 103)**

The "Wray" binocular magnifier, manufactured by **P. W. Allen and Co.,** 253 Liverpool Road, London, N.1, to fill the gap between the single lens and the microscope, is now available with a new series of mountings, including weighted-base, clamp- and screw-on types. Others under development include magnetic types, and floor stands. The instrument has a 100x magnification at 7 in., and a field of view of ¼ in. diameter. **(B 104)**

A chemical balance, the "Minor," has been developed by **Griffin and George, Ltd.,** Ealing Road, Alperton, Middlesex, as the first of a new series intended for general purposes but incorporating analytical features. Single-limb bows carrying the pans, an inclined scale that rises with the pointer to avoid parallax, and improved protection for agate bearings are some of the good features. **(B 105)**

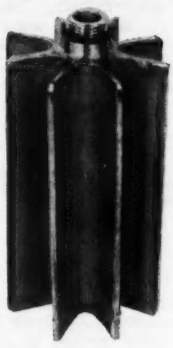
West Instrument, Ltd., 52 Regent Street, Brighton, 1, Sussex, who have hitherto specialized in temperature measurement and control for process work above 200°C, have entered the low-temperature field with a new design of proportional controller and indicator for precision work at below −100°C. **(B 106)**

Thin-wall stainless-steel fittings for butt-welded piping systems are being produced by **Wilmot Breeden, Ltd.,** Amington Road, Birmingham, 25. Standardization is so far on the two most widely used austenitic alloys, 304 L and 316 L, but the range can be produced in other alloys. Fittings are seamless where possible; they are otherwise formed from developed blanks and argon welded. All fittings are hydraulically tested; individual X-ray tests can be applied if desired. **(B 107)**

A portable mains-operated beta gauge is announced by **Baldwin Industrial Controls, Ltd.,** Dartford, Kent. Intended for use where the refinements of the standard beta gauge are not required, the design is simple and robust, and is calibrated in arbitrary units proportional to weight per unit area. Various types of measuring head mountings and alternative types of radioactive source are offered to suit particular requirements. **(B 108)**

PSS Filters

Porous stainless steel, in sheet form, is used for fabrication of filter elements made by Micro Metallic, a division of the Pall Corporation, of New York. Although this material is most popular in type 316 stainless steel (0.03% carbon) it is also available in nickel, monel, and a number of other alloys; in sheet form, as well as in finished filter units.



Porous stainless steel filter.

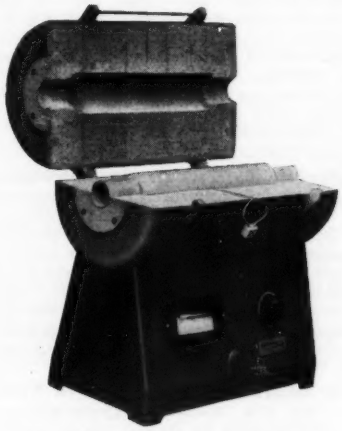
One of the outstanding features of this type of material is the high flow rate obtainable with a comparatively small pressure drop. For example, a square foot of $\frac{1}{16}$ in. thick material with a mean pore opening of 65μ will pass 330 ft³/min air, or 24 gal/min water, with a pressure differential of only 0.1 p.s.i. Six grades are available, the mean pore diameter varying from 165 to 5 μ (0.0065—0.0002 in.) and the standard design pressure for all filters is 125 p.s.i., although filters can be designed for operating pressures up to 10,000 p.s.i. Illustrated is a star-shaped filter, contained in a housing only 4 in. diameter; the length may be from 6-18 in.

(Micro Metallic, Division of Pall Corporation, 30 Sea Cliff Avenue, Glen Cove, N.Y. U.S.A.)

1291

Laboratory Tube Furnace

A new Catterson-Smith laboratory furnace for temperatures up to 1250°C, has a coiled-coil resistance winding cemented to the furnace tube. The aluminium casing and refractory insulation are split and hinged, for access to the tube or for speedy cooling when required. Furnaces are available (ex stock) in tube sizes of 1 × 12 in. to 2 × 18 in. in ratings of 1-2.25 kW. Energy regulators and pyrometers can be fitted, and combustion tubes of various sizes and grades can be supplied to fit inside the furnace tube, or lengthened heater tubes may be provided for inert gas pipes or seals.



New Catterson-Smith laboratory furnace.

(R. M. Catterson-Smith Ltd., Adams Bridge Works, South Way, Exhibition Grounds, Wembley, Middlesex.)

1292

Glass Phosphor

Activated glass, first developed by the British Scientific Instrument Research Association is now being produced by Levy-West Laboratories, and would appear to have possibilities for scintillation detectors, particularly in situations where resistance to acids and other corrosive substances are required. It has been stated that the material has somewhat similar properties to thallium-activated sodium iodide.

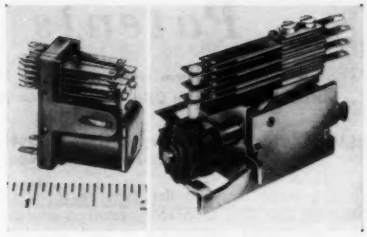
(Levy-West Laboratories Ltd., Wembley Hill Estate, Wembley, Middlesex.)

1293

New Relay Range

Nylon lifting pins, twinned gold-flashed contacts, plastics cases for transit and to act as dust covers, and a wide range of operating coils are some of the features of a new range of TMC-Zettler relays recently introduced. Types include the AZ210, a miniature relay of screwless construction which can be used at a switching frequency up to 50/sec; the AZ130, a reliable substitute for the P.O.3000 type relay where space is limited, and the AZ170, a latching relay operating and releasing contacts on successive pulses of the same polarity.

(Telephone Manufacturing Co., Ltd., Hollingsworth Works, Martell Road, Dulwich, London, S.E.21.)



Two of the new TMC relays; the AZ210 and the AZ170.

1294

Furnace "On Approval"

Companies considering the economics of electric smelting for ores of nickel, copper, manganese, iron, etc., can now try out the process without capital expenditure through a new scheme operated by Birlec-Efco (Melting), Ltd. At their Aldridge works an 8-ft diameter 350-kVA rotating-shell arc furnace has been installed which will be available on a hire basis for testing batches of material to determine their suitability for economic processing, it being possible to make a fairly accurate appraisal of what could be expected on a large-scale plant.

(Birlec-Efco (Melting), Ltd., Aldridge, Staffs.)

1295

CATALOGUES

From **B.K.L. Alloys, Ltd.,** comes a plastic-covered loose-leaf manual of their Tubend welding fittings, including elbows, bends, tees, reducers and caps, in carbon and alloy steels, monel and aluminium alloys. Tables giving comparisons of British and U.S. standards for carbon, ferritic, and austenitic alloys will be found particularly valuable, as will information on materials for low-temperature service. (Birmingham Factory Centre, Kings Norton, Birmingham, 30.)

Slat-type conveyors and hydraulic pallet trucks are described in two new lists received from **J. Collis and Sons, Ltd.** Another list covers the Transveyor ball unit in 1-in. and 2-in. sizes, with either rigid or cushioned-type mountings. (Regent Square, Gray's Inn Road, London, W.C.1.)

"The Case-Hardening of Nickel Alloy Steels." is the title of a publication received from **The Mond Nickel Co., Ltd.,** dealing with different methods of carburizing, heat treatment after carburizing, defects and their prevention, the influence of case depth on fatigue strength and suitable types of steel, both British and U.S. (Thames House, Millbank, London, S.W.1.)

"Batching Plant," a new brochure from **Thos. W. Ward, Ltd.** (Materials Handling Division) describes the various types of batch and continuous mixing plants available, including small portable batching units, cement silos and conveyors. (Albion Works, Sheffield.)

Rapier self-priming water pumps of the transportable type, for petrol, diesel, electric or independent drive, in capacities from 10,000-25,000 gal/h are described in new leaflets from **Ransomes and Rapier, Ltd.** (32 Victoria Street, London, S.W.1.)

The first number of "Building with Steel," published quarterly by the **British Constructional Steelwork Association**, has appeared. It contains an interesting article on structural steel in the nuclear industry.

Publication MA3, showing a few uses of asbestos millboard has been issued by **Turner Brothers Asbestos Co., Ltd.** (P.O. Box No. 40, Rochdale.)

D. J. Equipment (Hersham), Ltd., have issued a leaflet on portable spot-welding equipment and accessories. The smallest unit weighs 14 lb and will weld up to two 16 s.w.g. mild-steel sheets. (43 Queens Road, Hersham, Walton-on-Thames, Surrey.)

"Rocol—First in Molybdenum Disulphide Lubrication," is the title of a booklet produced by **Rocol, Ltd.** (Rocol House, Swillington, Leeds.)

Applications of Ion-exchange resins and celluloses, materials available, and general information, are given in a new catalogue received from **Bio-Rad Laboratories.** (32nd and Griffin Avenue, Richmond, California.)

A loose-leaf manual on the selection and application of bronze alloys has been published by **J. Stone and Co. (Charlton), Ltd.** (Charlton, S.E.7.)

Particulars of a new unstabilized laboratory power pack with voltage control in three ranges is given in a leaflet PV-250-B issued by **Claude Lyons, Ltd.** (Valley Works, Ware Road, Hoddesdon, Herts.)

Complete information on Drallim control valves, pipe couplings, flow gauges, nylon tubing, in the form of specification sheets in a reference wallet have been issued by **Drallim Industries, Ltd.** (Station Works, Westhall Road, Upper Warlingham, Surrey.)

Centralized lubrication systems and their applications are described in a catalogue received from **Farvalube, Ltd.** Another brochure showing some typical installations of centralized lubrication systems has been received from an associated company—**Denco Engineering Services, Ltd.** (Holmer Road, Hereford.)

From Ilford, Ltd., comes a new catalogue of industrial X-ray films, processing equipment and accessories. (Ilford, Essex.)

Full technical details of the 34 types of welding rod and 18 types of flux in the Sifbronze range are given in a new edition of their "Specifications" list, No. 91259C, issued by the **Suffolk Iron Foundry (1920), Ltd.** (Sifbronze Works, Stowmarket, Suffolk.)

Physical, mechanical, and electrical properties and suggested applications of all types of M.S. silicone fluids are given in a new booklet "Engineering Guide to Silicone Fluids," published by **Midland Silicones, Ltd.** (68 Knightsbridge, London, S.W.1.)

"Paxolin Tubes and Cylinders," is a new booklet giving technical details, standard sizes, and hints on machining, issued by **The Micanite and Insulators Co., Ltd.** (Empire Works, Blackhorse Lane, Walthamstow, London, E.17.)

"Varimag" magnetic amplifier variable-speed motor control is described in a booklet issued by **Lancashire Dynamo Nevelin, Ltd.** (Hurst Green, Oxted, Surrey.)

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. 6d. each (including postage).

B.P. 817,067. Laboratory nuclear reactor. To: North American Aviation Inc. (U.S.A.).

A low-cost water-boiler type reactor for training and as a laboratory neutron source. A core vessel containing a fuel solution (aqueous uranyl sulphate) through which pass horizontally arranged experimental tubes and above which is an overflow canopy, is mounted in a lead case acting as a gamma shield and also as an efficient neutron reflector. Due to proximity of the core only a minimum of lead is required taking up only 1/15 of the usual volume of graphite, and weighing one quarter as much as a pure graphite reflector. The lead case is fabricated by pouring molten lead into a thin aluminium mould retained in the assembly. The assembly is suspended in a tank containing ordinary (light) water on three vertical steel tubes. The water tank serves as principal neutron shield. Two vertical control rods are provided in tubular steel containers passing through the core. Conventional reactor control circuits may be employed.

B.P. 817,481. Ionization chambers. E. K. Cole Ltd., R. G. Davis.

The output of a chamber used in conjunction with a source of beta radiation for thickness measuring purposes is increased by lining or coating the inside of the chamber of aluminium or other light alloy with lead or lead paint. The coating should be of semi-infinite thickness or slightly greater (where the expression " semi-infinite " means half the value of " infinite " thickness, i.e., the minimum thickness of a plate preventing the passage of any data radiation from a radioactive source). Three coatings of red lead paint will usually be sufficient. Lead foil of 0.22 in. thickness may also be used or metallic lead sprayed on the inner surface of the chamber.

B.P. 817,593. Beta ray measuring gauges. E. K. Cole Ltd., R. G. Davis.

Two ionization chambers enclosed by a common collector electrode with a dividing wall of insulating material, each chamber housing a polarizing electrode. Air or gas may flow from one chamber to the other but beta radiation entering one chamber is prevented from passing to the other chamber. A metal container insulated from the collector electrode serves as an earthed screen.

B.P. 817,681. Gas discharge apparatus for producing thermonuclear reactions. Sir George P. Thomson, M. Blackman. To: U.K. Atomic Energy Authority.

By means of magnetic or electric fields a pressure gradient is established in an ionized gas of low density and high particle energy, the gradient falling in all radial directions from a central point, or in all directions normal to a circular or other endless axis within the gas. Provision is made for maintaining the electrons at high speed in an endless path to set a field to contain the gas. The circulating electrons constitute a closed loop of heavy current. The nuclei of the gas are bound to the electron stream by electrostatic attraction, and suffer only a minor loss of energy by bombardment, so that their energy can be continuously increased over a substantial period of time, e.g. by injecting electromagnetic waves to be absorbed by the ionized gas. The apparatus comprises a toroidal vessel for containing a fuel gas at low density, energizing means for constituting a closed current loop, and means for stabilizing the current loop within the vessel to isolate the fuel gas nuclei from the vessel walls while their energy of random motion is increased to a level at which thermonuclear reactions take place.

B.P. 817,753. Neutron detector. To: U.K. Atomic Energy Authority (U.S.A.).

A thermocouple (thermopile) responsive to neutron radiation and an indicator. The hot junction of the thermocouple preferably carries material of high neutron capture capabilities (boron).

B.P. 817,759. Radiation monitoring devices. D. Allenden, I. W. Collip. To: Assoc. Electrical Industries, Ltd.

In devices operating with an ionization chamber discharged by exposure to gamma or X-radiation followed by an audible warning signal, it is difficult to know if the device is functioning properly, as leakage currents may exist which reduce efficiency. This difficulty is overcome by an electronic control device responsive to the state of an initially charged ionization chamber. The device is normally non-conductive but conducts when the charge on the chamber falls below a predetermined level on exposure to radiation. An oscillator producing an audible signal is controlled so as to raise the signal note when the device becomes conductive. As control device, thermionic electrometer valve with at least two grid electrodes may be used.

B.P. 817,861. Separation of fission products from irradiated uranium. To: U.K. Atomic Energy Authority (Canada).

Neutron-irradiated uranium is heated under vacuum to above 1,130°C. The fission products distil off, are condensed and recovered.

B.P. 817,872. Pumps. H. F. Parker. To: U.K. Atomic Energy Authority.

This simple constant-volume feed pump for radioactive liquid has no valve parts which may stick and is characterized by a cylinder with a blind end below a constant level of liquid in a tank, from which liquid flows by gravity into the cylinder, and an open end above the constant level. A leaky plunger reciprocates in the cylinder, discharging at a level higher than the constant level liquid displaced by its downward stroke.

Pumps may be ganged together to feed liquids into a system with a fixed ratio of volume between the liquids. Adjustment of the ratio is then effected by adjusting the relative length of stroke of the pumps.

B.P. 817,895. Source of radioactive energy, and method of producing the same. P. Alexy (Germany).

A rigid body of carbon, activated carbon, or graphite, in compressed form, is used as carrier for a radioactive substance uniformly distributed within it, e.g., by impregnating it with the radioactive substance in a vacuum. The carrier may be produced as a porous body from a mixture of carbon and ceramic or vitreous or metallic materials (metal oxides) by compressing a pulverized mixture and sintering it. It may be coated in parts with a radiation absorbing coating (zirconium). A liquid- and gas-tight coating may be applied to prevent evaporation, without screening radiation.

B.P. 817,918. Manufacturing radiation-sensitive sintered bodies containing cadmium sulphide. To: Philips Electrical Industries, Ltd. (Netherlands).

A mixture of cadmium sulphide and cadmium oxide powders containing at least 0.1% by weight of cadmium oxide is formed into the desired shape and sintered at 700 to 1,200°C in a neutral atmosphere (nitrogen or argon).

B.P. 817,963. Heat transfer system. L. A. Husain. To: U.K. Atomic Energy Authority.

A transversely finned body is provided with one or more baffles (inclined to the direction of flow) intersecting at least an outer portion of each fin, and extending outwardly so as to give a transverse component of motion to at least an inner layer of the heat-transfer fluid. In the usual arrangement of fuel rods in circular channels, the baffles may be helical.

B.P. 818,191. Treatment of metals in powder form. P. B. Eyre, J. Jackson. To: U.K. Atomic Energy Authority.

Conversion into spherical masses by moistening the powder with alcohol, or an aliphatic acid ester, or a liquid hydrocarbon, vibrating the aggregates, dispersing them in an oxide of an alkaline earth metal (magnesium oxide, aluminium oxide) and heating to drive off liquid, then heating again to cause the powder to coalesce.

B.P. 818,258. Process for the manufacture of an encased fuel element for nuclear reactors. To: Deutsche Gold-und Silber-Scheideanstalt vorm. Roessler (Germany).

Fissionable material (uranium) is introduced into a can of metal with a melting point higher than that of uranium (zirconium, columbium or steel). The fissionable material can then be welded homogeneously to the can material without the use of a solder, e.g., by melting under high vacuum in an electric furnace a rod of uranium, which has been placed in a zirconium can with a slight clearance, after having freed the rod from any oxide layer by electro-polishing.

B.P. 818,272. Packings for liquid-liquid extraction columns. D. H. Logsdail. To: U.K. Atomic Energy Authority.

In a stack of superposed spaced flat perforated screens arranged to fill the column, there are interposed at regular intervals (each 4th or 5th screen) perforated conical plates. This counteracts the tendency for the dispersed phase to stream preferentially through collinear perforations in consecutive screens.

B.P. 818,312. Metal coatings. L. M. Wyatt. To: U.K. Atomic Energy Authority.

Fuel elements for nuclear reactor can be produced by packing metal powder (beryllium) round the fuel to be coated (metallic uranium or thorium, their oxides or carbides) and forging the assembly in a die at a temperature below the melting point of the metal powder. The die is made of a material (mild steel) deformable at forging temperature (1,000-1,200 deg. C. for a beryllium coating).